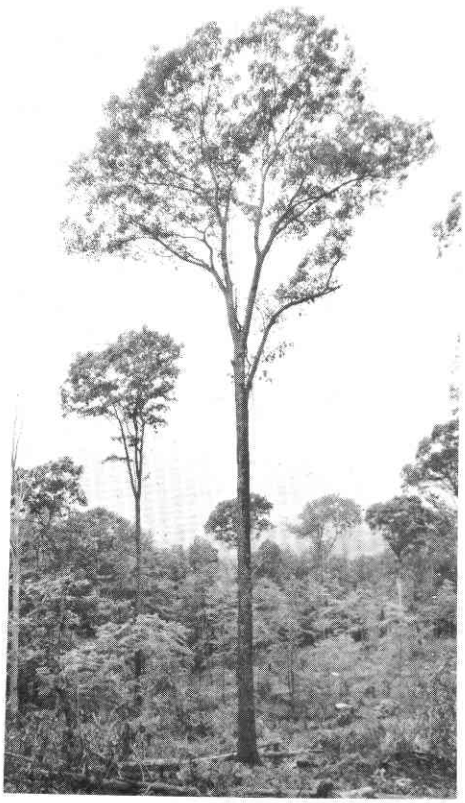
OAK
SYMPOSIUM PROCEEDINGS



NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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WARREN T. DOOLITTLE, DIRECTOR

THE OAK SYMPOSIUM

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West Virginia University

Forest Service, U. S. Department of Agriculture

Appalachian Hardwood Manufacturers

West Virginia Department of Natural Resources

FOREWORD

AS "tall oaks from little acorns grow", the germ of an idea blossomed into this symposium on the five upland oaks. Called simply the "Oak Symposium", that's what it's all about — a meeting to bring together a summation of the advances made on the silviculture, management, and utilization of the upland oaks. Part of this process is the pinpointing of what we don't know — gaps in our knowledge that research can help fill.

Certainly the oaks as a group are one of our most valuable hardwood resources, amounting to one-third of the hardwood sawtimber volume in the United States and almost 10 percent of our total growing-stock volume. The topics covered in this symposium — from the historical significance of the oaks to more mundane subjects dealing with the applied aspects of oak culture — present a broad prospectus of our knowledge, indicating that we know a great deal about growing and utilizing this resource.

But we cannot rest on our laurels. Much of our present knowledge has not found its way into practice, and there is still much to be learned about managing the oaks as a timber resource. Perhaps more important, we must continue to face the challenge of applying what we do know to increase contributions of the oak forests to other social values. We are in an era when timber production is no longer the primary objective of many forest owners. Aesthetics, watershed management, recreation, and wildlife are goals given equal or greater priority by many; and we must also keep in mind the use of upland oaks as ornamentals for the improvement of urban environments. At the same time, we have to recognize that these nontimber uses dictate further intensification of oak timber management if the demands of a wood-hungry society are to be met.

A symposium of this sort does not come into being without growing pains. Two years in the making, the efforts of the sponsors — West Virginia University; the USDA Forest Service; the Appalachian Hardwood Manufacturers; and the West Virginia Department of Natural Resources — and the individuals behind those efforts, should be commended. And, of course, without the enthusiastic participation of the experts invited to present papers, and the discussion moderators, there could be no Symposium.

— D. E. WHITE and B. A. ROACH
Co-chairmen, Oak Symposium

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THE SPECIES and THEIR NAMES

To avoid needless repetition of the scientific names of the tree species mentioned in the Symposium papers, only the common names are used in the Proceedings. Here are both the common and scientific names of the species mentioned in these Proceedings.

THE OAKS

Black oak	*Quercus velutina* Lam.
Blackjack oak	*Q. marilandica* Muenchh.
Bur oak	*Q. macrocarpa* Michx.
Cherrybark oak	*Q. falcata* var. *pagodaefolia* Ell.
Chestnut oak	*Q. prinus* L.
Chinkapin oak	*Q. muehlenbergii* Engelm.
Durand oak	*Q. durandii* Buckl.
English oak	*Q. robur* L.
European turkey oak	*Q. cerris* L.
Gambel oak	*Q. gambelii* Nutt.
Laurel oak	*Q. laurifolia* Michx.
Live oak	*Q. virginiana* Mill.
Northern pin oak	*Q. ellipsoidalis* E. J. Hill
Northern red oak	*Q. rubra* L.
Nuttall oak	*Q. nuttallii* Palmer
Overcup oak	*Q. lyrata* Walt.
Pin oak	*Q. palustris* Muenchh.
Post oak	*Q. stellata* Wangenh.
Scarlet oak	*Q. coccinea* Muenchh.
Shingle oak	*Q. imbricaria* Michx.
Shumard oak	*Q. shumardii* Buckl.
Southern red oak	*Q. falcata* Michx.
Swamp chestnut oak	*Q. michauxii* Nutt.
Swamp white oak	*Q. bicolor* Willd.
Water oak	*Q. nigra* L.
White oak	*Q. alba* L.
Willow oak	*Q. phellos* L.

OTHER SPECIES

Black gum	*Nyssa sylvatica* Marsh.
Black locust	*Robinia pseudoacacia* L.
Black walnut	*Juglans nigra* L.
Red maple	*Acer rubrum* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees
White ash	*Fraxinus americana* L.
Yellow-poplar	*Liriodendron tulipifera* L.

THE HISTORICAL SIGNIFICANCE OF OAK

by J. V. THIRGOOD, *Faculty of Forestry, University of British Columbia, Vancouver 8, B. C., Canada.*

ABSTRACT. A brief history of the importance of oak in Europe, contrasting the methods used in France and Britain to propagate the species and manage the forests for continued productivity. The significance of oak as a strategic resource during the sailing-ship era is stressed, and mention is made of the early development of oak management in North America. The international trade in oak logs and lumber is also discussed.

HAVING BEEN ASKED to speak on the importance of oak in Europe from earliest times—the uses of oak wood and forests, the methods of handling oak stands to propagate the species, natural and artificial cultural methods, and other significant management practices, and the early uses of oak and treatment of oak stands as forestry developed in the United States—I feel somewhat like a certain Egyptian mummy: pressed for time. For the story of oak is the story of European forestry and, to a large extent, the story of Europe itself.

Oak, the strategic resource and the essential commodity of domestic and industrial life, has been a major factor in the evolution of the European people and in the struggle of the great powers for dominance.

I would have wished to trace the management, commerce, use, and strategic importance of the tree through the classical period. I am tempted also to look to the maritime states of the Medieval and Renaissance periods; for the great fleets of the Byzantines, the Turks, the Italian maritime states—and the pirate flotillas—were dependent on oak.

Unfortunately, time does not permit; so I must restrict myself to western Europe and, more specifically, to France and England, for long the principal protagonists on the world scene. Their contrasting attitudes toward oak management provide several nice lessons. I will also touch on the development of world trade in oak lumber. Even within these limits I can only introduce the subject.

FRANCE

Woolsey *(1920)* and Reed *(1954)* provide comprehensive accounts of present-day French forestry, while Osmaston *(1968)* in his chapter "Development of Forest Management" gives an excellent discussion of the evolution of European silviculture and forest management. I have drawn extensively, though not exclusively, from these sources.

Modern France is almost the sole quantity producer of fine-quality oak, and oak is still the largest component of the French forests.

Today one-fifth of France is under forest, and oak comprises 25 percent of this. Of 301 representative forests of over 5,000 acres, 246 have oak as their dominant species.

The primitive landscape comprised a broadleaf forest with oak predominating. Clearances began with the arrival of the Bronze Age Gauls, about 1000 B.C. At the time of Caesar two-thirds of the country was still under forest. Wide belts of trees formed frontier zones between the tribes. The center of the country contained the oak forests that were important in the Celtic religion. For the Gauls the oak was sacred. Trees with mistletoe had been visited by the gods. Only the Druids could enter the sacred groves. The name Druid is derived from the Celtic word *deru*—oak.

The Romans were ill prepared for the northern forests. These forests were the antithesis of civilization. To tame the forest and its inhabitants, the Romans divided it up with roads and brought it to manageable proportions. The disagreeable problems of jungle warfare and the psychological dread of the mystery and darkness were reduced.

The settled lands and adjacent forests were apportioned to the nobles; but tenants and serfs enjoyed rights to fuelwood, timber, and grazing. Areas reserved to the landowner were *foris*—outside the areas of common rights. The vast unorganized tracts, more than half the total forest area, common property or—better—nonproperty under the Gauls, were Imperial domain. Here time-served legionaries and immigrant tribes were settled, and the prevailing philosophy was "*Quid est agricola?*" "*Silvae adversarius*". What is the farmer? The foe of the forest.

The trees sheltered more than barbarians, gods, and Druids; they also fed great herds of swine that provided the principal meat supply of the Gauls and an export trade in salted pork with the cities of Italy.

With the retreat of Roman rule, whole communities disappeared. Not till the 6th century was the advance of the forest stopped. The principal enemy now was not the Roman legions but the Roman church. Land reclamation became one of the recognized duties of monastic life. By the 8th century one-third of the total area of France had passed to the Church, which remained the greatest single forest owner until the Revolution of 1789.

The Early Forests

A conflict of interest developed between the peasant-cultivator and the great lords. Medieval game laws were severe. The value of the forest lay in its potential for agricultural clearances and for the chase; but slowly the intrinsic value of woods for timber and pannage became recognized. Throughout the Middle Ages the forests were also the refuge of the outcasts of society. Europe was plagued by bands of outlaws, and every region had its legendary Robin Hood.

The net result of reclamation and colonization was the transformation of the rural economy. The forests began to appear as great wooded islands in a sea of cultivated land. In time of war or plague, the forest expanded. In the 14th century, population fell by half and even to one-third. It was said that "the forest returned with the English".

Forest law continued to develop. Common rights became firmly established. Indicative of values is that while deadwood might include also living trees such as alder and thorn, rights never extended to the cutting of the oak or beech that provided the pannage. Forests were often measured in terms of swine, one pig representing 2½ to 4 acres depending on the quality of the wood. Certain areas were the absolute reserve of the owner. On the feudal estate, timber could be cut only with permission and for personal use.

By the 16th century there were local shortages of oak timber. Forest legislation was still closely tied to the game laws. The feudal *droit de garenne* provided a slight check on the threat to the survival of the forest. The pace of industrial life was quickening. Wood ash was needed for glass works and soap manufacturies; timber was required for mining. Artisans established themselves in the forests—charcoal burners, iron smelters, sabot-makers, and woodworkers of all kinds. Also there were the

trade guilds or *compangnonnages,* tanners who demanded oak bark, weavers and bakers who had prescriptive right to wood for looms and furnaces. By the 14th century the population reached 20 million, and since then the rural population has probably changed little. The forests covered 13 million hectares or only 2 million more than today.

In the early Middle Ages, France's timber needs had been relatively small and could be met from agricultural clearances. The central parts of the forests were reserved for hunting. By mid-13th century, regular timber fellings had become financially necessary in the royal forests, providing the government with a quarter of its revenue. One hundred years later the coastal forests of Normandy were being systematically exploited for naval timber. The unregulated selective fellings *(Furetages)* were difficult to control.

The problems of management were (1) to control right holders who made excessive demands on the forest and whose animals destroyed recruitment; (2) to prevent abuses in the small scattered high forest *coupes* and selective fellings where fraud and corruption were both easy and common; and (3) to obtain seedling regeneration.

Controls Developed

Coppice management, practiced since at least the time of Charlemagne in the early 9th century and by the Romans prior to that, was well understood. Coppice requires careful treatment if it is to be kept productive. Maiden trees have to be stored to provide for the replacement of wornout stools. Great significance is attached to maintaining a proper proportion of these trees of appropriate ages, and the method becomes coppice with standards.

Controls developed early. These methods were now adapted to the high forest. The many ordinances from 1280 to 1597 illustrate the evolution. Yields were limited to the *possibilité.* Annual *coupes* were prescribed, not by numbers of trees as previously but by area (*aire*) of 10 to 15 hectares. Coupes were surveyed and clearly delineated by hammer-marked boundary and corner trees selected from the best oaks. An additional minimum of 6 to 8 seed trees were reserved per acre. Fellings were done with care to facilitate regeneration. Coupes were enclosed by hedges or fences to exclude grazing, and hunting was regulated.

The positioning of the high forest coupes was important. For more than a hundred years these *coupes à aire* were made without fixed plan. In the 16th century it was prescribed that they be located where the stand required regeneration. These scattered coupes caused confusion. Ordinances of 1544 and 1597 stipulated that coupes be *de proche en proche, à tire et aire.* That is, annual coupes by area, in felling series, had to have at least one boundary contiguous and coincident (*à tire*) with the previous coupe, and successive coupes had to proceed in the same general direction.

This formalized yet simple *tire et aire* system was necessary to maintain order in working unmapped high forest without a network of roads and rides; also it provided an orderly sequence of age-gradations moving steadily around the forest, which later enable the development of periodic blocks. By the mid-16th century an organized forest administration and ordered silvicultural management had been developed in the royal broadleaf forests. Silvicultural techniques were advanced and thorough, including retention of an adequate number of seed sources, cultivation and supplementary hand-seeding, conservation of advance recruitment, a 10-year cleaning cycle, enrichment sowing and planting, and improvement fellings to remove deteriorating seed trees and "wolves" and undesirable coppice and inferior species. It was recognized that, "like a woman, a tree becomes barren with age".

Unfortunately "national emergencies" were endemic and the *coupes ordinaires* were suspended all too often in favour of *coupes extraordinaires,* which meant the cutting of larger areas than was prescribed in the management plan.

Forests Depleted

In the 17th century the progress made was lost. A corrupt staff overcut the for-

ests, and silviculture was neglected. The royal forests were being despoiled or maladministered, or both. There were periodic attempts at reformation. The tradition of the "quarter in reserve" originates from this period.

Despite all such measures, forests were seriously depleted to satisfy the growing industrial and domestic demands and to line the pockets of the forest officers. In 1661, Colbert, Comptroller of Finance to Louis XIV, took hold. His words, "France will perish for lack of timber", were potent. Equally potent was his installation of the guillotine in the naval dockyards. The forests across the nation were closed for 3 months when his special commissioners reported on areas and stocking and obtained an accounting of all fellings and alienations since 1635.

The outcome was the famous *Ordonnance de Eaux et Forêts de 1669*, a masterpiece of forestry administration. The forest service was reformed from top to bottom. The grand masters were dismissed; many were sent to the galleys. The *tire et aire* system was reaffirmed with controls that yet provided for the evolution of silvicultural practices.

In the 18th century forestry again went into a decline. Several famines led to agricultural clearances. Recurring naval wars and increased expenditures led to fellings unprofitable to state and to private owner. To make good the losses of the Seven Years War, the Office of Marine was authorized to conduct fellings on its own account. This was done without regard to the forest. Whole areas were felled and left desolate, the practice of leaving tellers was abandoned, and natural regeneration aborted. By the time of the Revolution of 1789 the forests had suffered greatly. In the royal forests 70,000 hectares had been lost in 20 years. Timber had to be imported. The Revolution removed remaining restraints. Widespread devastation followed. Fellings were also necessitated to replenish the Navy and Exchequer.

The oak rotation had been reduced to 75 years. Large areas degenerated into coppice or scrub. New methods were needed. Duhamel du Monceau advised that poor sites should be clearcut, burnt, and a crop of lucerne grown prior to reseeding. This was an improvement on unconsidered *tire et aire*, but it took no account of the need to provide shade and protection to the young crop. It was also expensive and involved several years of careful maintenance. The proper solution was not worked out until the early 19th century.

In 1827 came the *Code Forestier*, a revision of the Ordinance of 1669. Coupled with this was the establishment of *L'Ecole National des Eaux et Forêts* at Nancy. Nancy's contribution was largely responsible for the 19th century rennaissance of French forestry.

New Ideas Arise

While 18th century France was preoccupied with political affairs, new ideas about forestry were generating in Middle Europe. The first Director at Nancy, Bernard Lorentz, had studied under Hartig; and he and his successor, Parade-Soubeirol, a pupil of Cotta, advocated the adoption of *la method allemande*. Inherent was the recognition that "natural regeneration" is not natural—the process has to be directed and manipulated. Essentially the oak forests were to be managed by a method of progressive fellings, a "system of natural regeneration and thinning", or shelterwood. The technique is better known as the "Regular or Uniform System". The French still prefer the term *method de regeneration par coupes progressives*. This method is an evolution of *tire et aire*. The chief points of difference are a greater attention to the opening of the canopy for regeneration, removal of all overwood when regeneration is established—i.e. a departure from *tire et aire* where the seed trees were left to grow through the next rotation—and more attention to thinnings to favor crop trees. By the middle of the 19th century the Uniform System had ousted *tire et aire* from the oak forests.

Thus 18th century French foresters had grasped the basic principles of forest management. They had explored the relations between yield and increment, the properties of the even-aged normal forest designed

for sustained yields, the regulation of the cut by volume as well as by area, and the effect of compound interest on profits. They knew the need for legal definition and the constitution of the forest estate for its proper protection and organization for practical working. Forests were surveyed, demarcated, and divided into felling series, which were divided into compartments aggregated into periodic blocks suited to the rotation. The question was: What would be the main direction of the next move in forest management? Toward the silvicultural variety made possible by flexible yield regulation? Or toward a more rigid forest planned for ease of utilization and the best financial yields?

It might here be remarked that French silviculture is characterized by simplicity, Gallic elan, and a refreshing lack of dogma. Where the central European author may describe 20 or 30 different cutting systems, French silviculturists limit themselves to a comparative few. They leave special methods or variations to the individual forester who uses his judgment in varying standard systems so as to meet local circumstances. These local methods they described in the forest working plan.

The volumetric complications used by Hartig were repugnant to the French, with their love of practical clarity; so it was the area methods used by Cotta for the allotment of periodic blocks that were developed in France. The advantages of permanent, compact periodic blocks in which different operations could be concentrated, and which led the forest to normality in one operation, greatly appealed and were enthusiastically adopted. The sacrifices involved in the formation of a permanent pattern of periodic blocks were small in *tire et aire* forests with their series of continuous age gradations. Fixed periodic blocks were undisputed until about 1880, when the drawbacks of their rigidity became apparent.

The French continued to recognize the advantages of even-aged forestry, so the methods introduced for greater flexibility still aimed at uniform stands. With comparatively large administrative charges, French foresters do not favor intricate felling patterns or the intensive working of the selection system. Revocable and single (floating) periodic blocks replaced the fixed periodic blocks in the oak forests. These new methods enabled rotations to be varied from compartment to compartment, but all aimed at stand uniformity. It is of interest that despite their preference for even-aged forestry, French silviculturists did not clearcut and plant on any large scale in pusuit of the soil-rent theory; thus the ill effects of the spruce mania were avoided.

An Example of French Oak Management

The Uniform System, with local variants, may be seen today in most of the great oak forests of central France. The Forest of Troncais is one of the finest. It covers 26,250 acres. Colbert's naval commissioners had found only 370 acres of good high forest. Wide stretches were derelict, carrying broom and heather. The poor growth was cut back, leaving only a few of the best trees as reserves; the rotation was fixed at 200 years; and the whole area was treated as high forest.

Unfortunately within 100 years the success obtained induced the government to lease two-thirds of the forest to an iron foundry. These alienations were worked as coppice on a 45-year rotation. With the Revolution, Colbert's prescriptions were ignored. In 1835, Nancy-trained foresters, guided by the third of the forest that had been excluded from the smelter lease, returned to the 17th century prescriptions. In those compartments that had never been converted to coppice, the *amenagement* has never been altered. The only modification has been to extend the rotation from 200 to 250 years; otherwise the original prescriptions are still operative. On the degraded areas 1,250 acres were planted to pine around 1850. Half of these have been returned to oak.

The trees on the third unaffected by the 18th century aberrations are being harvested. Prices are instructive. At an auction in 1953, twenty-nine trees realized 11¼ francs (nearly $35,000 at the then rate of

exchange). In 1959, 2½ million francs ($9,000) was paid for one tree. This was 310 years old, 92 feet to the crown, and 14 feet in girth. At 36 feet the trunk forked; each fork measured 8¼ feet in girth. In this forest the average tree sold contains 250 cubic feet of good timber. These sales attracted buyers from all of France and abroad.

The details of the Troncais Uniform System are as follows: At rotation end there are about fifty-five 250-year-old trees to the acre. A small proportion of 150-year-old beech and hornbeam form an understory for soiling values and to keep the oak clean. The floor is shaded and bare of vegetation. A *coupe d'ensemencement* (seeding felling) removes about a third of the volume. The pedunculate oak is removed as well as the beech and hornbeam to ensure the regeneration of the less prolific sessile oak. The resulting seedfall produces a *brosse* of regeneration. Three to 8 years later a *coupe secondaire* removes the seed trees. There may be one to three of these fellings. Some trees are left to reseed the gaps left by the secondary fellings, and the final felling is made when the young crop is complete. The interval between first and final cuttings is between 12 and 18 years. Care is necessary to prevent weed invasion into overlarge openings. The gaps left by the last trees are cultivated and planted.

All trees are branched and then felled by *culée noire*. The roots are cut below ground level, and the ground is leveled and left clear of stumps.

In the new crop, beech and hornbeam are cut back at 5-year intervals until the oak is 40 years old. From 40 years the thinning cycle is extended to 10 years, and the understory is allowed to grow up.

Year	*Stocking (No. of trees)*	*Cubic-feet per acre*
At establishment	12,000	—
30	4,000	—
50	700	2,824
100	160	5,360
150	90	7,060
225	55	11,260

A fixed periodic block was used initially, but in 1928 a floating periodic block was introduced for greater flexibility. A thinning experiment illustrates the precision and long-term nature of the enterprise. The objective is to produce trees with larger girth through more drastic thinning. From age 50 heavier thinnings are adopted, and at 100 years the stands will contain a maximum of 120 trees per acre instead of the present 160 to 190. At 200 years the final crop will contain 48 trees measuring 9,896 cubic feet as against the normal stand of 60 trees measuring 8,900 cubic feet.

Conservatism Justified

Certain features of French forest administration should be emphasized. The state forests are almost invariably managed on longer rotations than are private forests. Traditionally communal and private woods have been coppice, heavily cut on short rotations, with high interest rates and inferior products. Early this century, when eight-tenths of private forest was coppice, losses due to coppice management were $60 million a year. Even in the state forests one-third of the producing forest was coppice with standards.

Today coppice comprises one-third of the total forest area, and an area only slightly smaller is under coppice with standards. State rotations are clearly non-financial. The basic premise is that in a great country commerce requires wood of large size. State ownership alone can accept this situation of low returns for general welfare.

The wisdom of holding such stocks, and of the "quarter in reserve", is said to be borne out by France's past history. Despite the demands of two World Wars, of trench warfare and the Occupation, the forests have been able to meet national demands. In recent times some change is becoming apparent; nevertheless the French forester is far from accepting the economic principles that increasingly dominate North American, Scandinavian, or British forestry. Perhaps with his sense of history he is not overly impressed by transient values.

A quotation from the American forester, Theodore S. Woolsey, sums up the attitude of the French forester:

> The art of the French forester lies in his keen perception of his objectives and in his simple methods. He deals with stands

rather than trees. In the regulation of the yield he computes the cut with admittedly inaccurate formula — but he gets the required results — a reasonably equal annual cut — and he realizes that with frequent inventories the inaccuracies of the formula will be corrected. His mensuration is a rough guess, many refinements considered essential in the United States even with its extensive conditions are omitted as unnecessary to the objective. If an error is made in estimating the volume of a sale this is taken up in the bidding.* Timber sales are kept small so as to give the small local mill a chance as well as to increase competition. No logging is done by the State. It is as a silviculturist that the French forester is best and regulation statistics are rarely allowed to interfere with silviculture.

In this necessarily brief account I have limited myself to the *tire et aire* and Uniform Silvicultural Systems. The interested reader should refer to Troup *(1952)* for other methods that are used where local conditions require. Inherent to all is the recognition that management and silviculture are intimately related. A rational silviculture, systematically applied, can be practiced only within the framework of the managed forest.

*The bidding Woolsey mentions is in auctions conducted according to the "Dutch System" of downward bidding. This is a sensitive procedure when dealing with high-priced materials in high demand.

ENGLAND

Until the last 50 years, British forestry developed differently from forestry in continental Europe. The striking differences are explainable in the context of British mercantile, industrial, and social traditions. Large-scale growing of trees on the European pattern rarely occurred outside a very few state forests, originally preserved for game and later for the supply of naval oak —and not always in these.

Oaks in England grow in small woods, hedgerows, and parks. Whereas the French forester dealt with forests, the English concern was with individual trees and small woods. Inherent in this arboricultural tradition was the care of landscape, and a concern that trees, even if planted primarily for economic reasons, should appear seemly.

Generations of landed proprietors have felt a positive affection for stag-headed old oaks. Sentiment allowed these trees to pass into a picturesque and decaying old age in spite of the entreaties of naval purveyors and timber merchants. The long-held national ideal has been the "great tree" with large crown and massive branches. Even today, to most English people the characteristic oak is the veteran of parkland and hedgerow rather than the straight-grown forest tree. Many such notable trees survive. There are records of trees with girths of 48 feet, containing 3,000 cubic feet of timber.

Lowland Britain originally had a deciduous forest in which oak predominated. Yet at the beginning of this century there were only 60,000 acres of Crown woodlands, and for the rest there was the familiar patchwork of private demesnes, small woods, copses, and hedgerows. In 1952 one-sixth of the national timber inventory was in hedgerows and in woods of less than 5 acres, equivalent to a forest of ¼ million acres. Oaks accounted for one-third of the total woodland area, one-third of the hedgerow trees, and one-third of the standing volume.

In England, forest did not imply trees, but a tract of land subject to the forest law, which, to the end of the 13th century, was concerned with the well-being of the deer, *ferae naturae*. The value of the forest had nothing to do with the growth of timber. Most forests were held by the Crown. By the time of Henry III, one-tenth of the country was so held. Other persons might possess lands within the bounds of the forest, but were not allowed the right of hunting or of cutting trees at their own will. The 13th century *Magna Carta* and the lesser known *Charte Forestie* redressed the balance to an extent, yet the severity of the game laws remained.

Aside from the chase, forest values lay in pannage. In about 1086 the Doomsday Commissioners asked, "How much wood?" A typical village entry says: "There is wood for forty swine"; so tax was levied accordingly. Some manors had wood for as many of 2,000 swine. Earlier a law of King

Ina (d. 726) had prescribed a fine of 30 shillings for felling a tree and double this if the tree was large enough for 30 hogs to shelter in its shade.

The Manorial Estate

The "waste" was essential to rural life. Customary rights varied, but there were privileges of wood for building and carpentry and fuel "by hook or by crook"—by pulling branches from standing trees. Villagers required timber to build cottages, to warm their hearths and cook their food, to make carts, ploughs, farm tools, and household furniture. The forests also meant pig pannage and extra pasture. Then as later, game swarmed—especially coneys or rabbits. On the King's forests, ever diminishing, and the enclosures, chases, and holts of the lords and gentry, ever increasing, severe game laws were enforced; and so was the less formal but equally drastic club law of the gamekeepers. Nevertheless, agricultural clearing for agriculture went on apace. In the words of an Anglo-Saxon poet, the plowman was "the enemy of the wood". By Chaucer's time 1340-1400, the woods of many manors had shrunk before the encroachments of "assert" farms.

The knowledge that oak yielded the best beams for building led the landlords to require the preservation of all oak saplings among their coppices. These were left to grow into standards and could be cut only on the express instructions of the lord of the manor. Every lord of the manor had need for oak trees to meet his tenants' lawful demands. The emphasis on individual trees is brought out by the documents of carpenters and the Medieval pipe rolls. Repeatedly we find gifts of oak trees by king, lord, or bishop for the construction of great buildings.

A Statute of Enclosure in 1482 permitting landowners to enclose coppice after each cutting indicates a recognition of timber values. Earthen banks planted with thorns were thrown up to exclude deer and cattle. On the dissolution of the monasteries, England saw the first wholesale felling of trees for timber purposes. Many woods passed into the hands of Henry VIII's courtiers. Many were promptly felled. In 1542 a Statute of Woods or Act for the Preservation of Woods was enacted. The preamble indicates the awareness:

> The King our sovereign, perceiving and right well knowing the great decay of timber and wood universally within the realm of England, and that, unless a speedy remedy in that behalf be provided, there is a great and manifest likelihood of scarcity and lack, as well as of building houses and ships, as for firewood:

This Act applied to all woods throughout England. It provided for exclusion of grazing and reservation of standards. Its result, with other successive Acts, was the enforcement of coppice with oak standards as the national system of silviculture, primarily for growing ship timbers. The system produced great branches and big crooks and curved timbers suitable for shipbuilding and for the construction of framed buildings. A result was that over the years everyone concerned with the growing of timber became convinced of the necessity of giving each individual tree a more or less free and isolated position. In time this principle came to be applied to all high-forest timber crops.

Wide Spacing

Thus from an early date, English practices have involved heavy thinning, or, at least, wide spacing. This was a significant difference from continental practice.

These methods of oak culture stimulated the Danish Count Reventlow's advocacy of High Thinning with emphasis on the release and development of selected individual trees and rapid growth, as opposed to the Low Thinning of Hartig, with emphasis on dense stands, closed canopies, and slow growth, that Reventlow attacked so strongly. Thus present-day concepts of heavy thinning can be traced to King Henry VIII's Act that ordained for England the coppice-with-standards method of growing timber trees for the production of naval timber.

This long emphasis on heavy thinning and wide spacing, with stimulation of heavy branch formation at the expense of long clean stems to meet the needs of a special market, has left considerable areas

of degenerate and unsalable scrub coppice and large-crowned oaks with massive branches. In retrospect it is amusing to read the report of the Royal Commission of 1786-1793. This strongly criticized the management of oak stands in the Forest of Dean. These had been ruined for want of proper thinning—they had been allowed to grow close with tall straight stems.

Many present-day British foresters would wish that more trees had been "ruined" by this "incorrect" thinning. But the wheel is turning full circle, and now there is an experiment in the same Forest of Dean to investigate the possibility of growing short-boled oak with large crowns for high-grade peeler logs on relatively short rotations. The 1786 commissioners would approve.

The open-grown character of English oak contributed to the vaunted superiority of the "hearts of oak" used in British men-of-war. Throughout the wooden ship era, English oak was strongly held to be more durable than French or Baltic (largely German) oak, particularly in the critical parts between wind and water, and less brittle. The significance of rapid growth for strength was recognized in the earliest writings.

From the mid-16th century the major concern was fear of a national shortage of oak. English forest policy from this time to the middle of the 19th century was primarily an effort to curb the extra-naval demands on the oak woods in the interests of the dockyard supply. Albion's *(1926)* study of the "timber problems" of the Royal Navy from 1626 to 1862, and of the impact of naval demands on the woods and political strategies of England provides the principal source of the maritime aspects discussed here, as it has for all other writers on the subject during the past 40 years.

Effect of Industry

During Elizabethan times particularly, a great expansion of mining took place, and these industrial activities were a considerable drain on the woods. Tanning was a thriving trade in every town and required quantities of tanbark. Quantities of wood and charcoal were burned in the new manufacture of glass. Measures such as the 1558 Act that "Timber shall not be felled to make coals for burning of iron", which prohibited the cutting of trees within 14 miles of the sea or any navigable stream, were ineffectual. There are many records of extensive wooded regions being deforested. Industrial works often had to be removed to fresh fuel sources.

The movement of industry then as now was not popular. The English iron-masters who turned to Wales when the Wealden iron works became exhausted were natural targets for tree-loving Celts. The Welsh poem *Coed Glyn Cynon* set the mood:

> Many an oak tree green of cloak
> (I'd like to choke the Saxon!)
> Is now a flaming heap of fire
> Where iron workers blacken.

Depletion was heavy. In Duffield Forest, 59,412 large oaks and 32,820 small ones in 1560 were reduced to 2,864 and 2,032 small in 1587. At St. Leonard's Forest in Sussex over a million cubic feet of timber was cut on royal license in 20 years. The yearly increase in shipping and the clear perception that England's future lay on the sea made it needful but difficult to maintain growing timber within reach of the dockyards. At least one galleon in the Armada had instructions to take and destroy the Forest of Dean to cripple the English Navy.

The shortages then as later lay in the great compass timbers. It was economically and even physically impossible to move great masses of timber for any distance, except by water. Though in upland districts there were still untouched "monumental" oaks, in other districts the disappearance of wood gave the cottager a cold house and a bread and cheese diet and restricted the manufacturer.

Coal came more and more into use for both industrial and domestic purposes, but in many areas there was a gap between the Wood Age and the Coal Age. Local wood shortages were common. In the reign of William III (1689-1702) cow dung was used as fuel in Leicestershire.

In the decade preceding the Civil War, the 300 ironworks in the country were consuming 300,000 loads (15 million cubic feet) of timber a year. To restrain the

waste of naval timber, a Surveyer of Iron Works was appointed. The early Stuarts saw the forests as a source of extra-parliamentary revenue, and Crown woods were sold as timber or alienated, often in the face of Parliamentary opposition. The Civil War and Commonwealth brought devastation. During the Commonwealth there was almost continuous naval war with the Dutch. Cromwell sequestrated the crown lands and great estates and built a great navy. But wooden ships decay faster than oaks can grow, so the Cromwellian shipbuilding orgy was followed by a dearth.

Naval Problems

The records of the New Forest in Hampshire clearly indicate the demands of the fleet. In a 1608 survey 123,927 oaks were registered for Navy use. By 1707 the Navy Survey could report only 12,476 oaks of ship quality. The other royal forests tell the same story. At East Bere from 15,274 oaks in 1608 there were only 256 in 1783. A single ship of the line required 4,000 well-grown oaks—150,000 cubic feet of timber.

Durability was not a virtue of wooden ship construction. The average life of a ship was 10 to 20 years before great repairs were necessary, in effect complete rebuilding. Many ships built under stress of war were of green wood. Ships started to rot almost upon entering water and required continual repair. One ship-of-the-line was scuttled by a sailor punching his fist through the hull. One third of the oak in the dockyards went for repairs.

Samuel Pepys, Secretary to the Navy Board under Charles II, described his inspection of a vessel in 1677 when he gathered "toadstools . . . as big as my fist". During the inspection of the Fleet in 1791 it was necessary to shovel away the dryrot before the timber could be seen. Rot often worked away at the futtocks just above the water line where the heavy guns were carried. The entire bottom fell out of the Royal George, one of the great ships of the sailing era.

The woodlands never fully recovered after the Cromwellian cutting.

The matter was referred to the newly formed Royal Society. In 1662 members heard John Evelyn lecture "Upon the Occasion of certain Quaeries propounded to that Illustrious Assembly, by the Honourable the Principle Officers and Commissioners of the Navy.." Two years later his *Sylva, or a Discourse on Forest Trees and the Propagation of Timber in his Majesty's dominions* was published. This book went through many editions and was a major influence on forestry for more than 200 years. Evelyn wrote, "Truly the waste and destruction of our woods has been so universal, that I can conceive nothing less than a universal plantation". Considerable private tree planting ensued.

Not all landowners devoted themselves to growing oak. One Restoration peer made the memorable comment that woods were "an excrescence of the earth provided by God for the payment of debts". Undoubtedly many immature stands were cut to raise money. Even the Master and Fellows of Queen's College, Cambridge, felled their timber to raise funds for the erection of a brewhouse. Fortunately for England the sense of family continuity, self-restraint, patriotism—and ready money—allowed the majority of landowners to grow their oaks to full maturity.

Demands for Oak

Most of the ships at Trafalgar were built of oaks grown as a result of Evelyn's efforts, assisted by exceptionally favorable economic conditions for the growing of oak timber between 1666 and 1700. The 18th century private planting interest was based not only on strategic needs and patriotic fervor, but also on a sound appreciation of the economic soundness of the venture when corn and wool prices were falling. Nevertheless there was competition between oak and corn. In 1544 Parliament had declared that "the turning of woodland into tillage is prohibited", but this was quite ineffectual against the enclosure movement.

The constraints of the tree exerted an important retarding influence on naval architecture. Between 1637 and 1860 the size and design of men-of-war changed very little, being determined by the sizes and shapes of the "Great" timbers. The stern post of a ship-of-the-line had to be

30 inches square and 36 feet long. Though masts could be composite, solid and naturally shaped pieces were required for constructional timbers. The outcome of naval engagements was determined not by superiority in ship construction but by the tactical skills of the admirals and the seamanship and gunnery of the sailors.

"Great" trees fetched very high prices, but landowners were not eager to grow oak to the considerable age necessary because the risk of decay was great. The high value of the large pieces scarcely compensated for the possibility of finding a dotard oak on felling. Trees were rooted up to use the roots for knees and crooks.

The management of the Royal Forests was characterized by feverish planting in times of crisis, alternating with long periods of neglect. Eleven thousand acres were enclosed and planted in 1668 under an Act for the Increase and Preservation of Timber within the Forest of Dean, the first real plantations made by an English government. There were other though generally smaller spurts of planting as after the Dutch Wars and the Fire of London, when it was said that the Norwegians warmed themselves by the Fire—an allusion to the quantities of Baltic timber that were imported in Norwegian ships. Similarly, after the Seven Years War in the mid-18th century, there was a timber shortage followed by a planting revival. Much oak was planted on unsuitable sites.

The demand for wood for other uses continued. In 1708 coal was first substituted for charcoal in smelting. By the end of the century less than a quarter of England's iron production was made with charcoal. Industry moved from the oakwoods of the south to the coalfields of the north. The general introduction of coal, with all its implications for the future industrial revolution, was hastened by the scarcity of naval timber.

Shortages continued. The Maritime Wars of the 17th and 18th centuries were a heavy and continuous drain. Numerous commissions were appointed to enquire into the state of the national forests and woods, yet still no consistent national forest policy emerged. In 1771 an Act for Efficiently Securing a Quantity of Oak Timbers for the Use of the Royal Navy was a prohibition on the building of merchant ships by the East India Company.

Era of Stagnation

The deplorable condition of the British ships during the War of Independence contributed largely to the outcome of the American Revolution. These poorly founded ships were unable to break the French blockade of the American coast. Though the loss of supplies of colonial masts was critical, the poor condition of the hulls also contributed. This was the only time during the long period of British naval dominance when England lost control of the seas and, consequent upon this, suffered her only defeat on land.

The poor condition of the British ships and the dependency upon American sources of supply in contrast to the better founded French squadrons, with the secured wood supply in the home forests, at least contributed to the ultimate result. There are accounts of ships so rotten that their hulls had to be strapped with cables to keep the planking in place. The Queen Charlotte of 1810 rotted before she could be put to sea. The Report of the Parliamentary Commissioners of 1782 said that in that year 2½ million cubic feet of oak timber were used in the dockyards. They recommended that another 100,000 acres of oak plantation be established.

In spite of these periodic resurgences of interest, depletion became progressively more alarming. During the Napoleonic Wars the fleet was in a shocking state, and the condition of the British ships at Trafalgar was deplorable. The Royal Forests had fallen into a notorious condition. In 57 years they supplied the Navy with the equivalent of only 4 years' consumption.

Finally in 1808 an official planting policy was adopted to enclose and plant 100,000 acres at the rate of 1,000 acres a year to meet forecast naval needs. This got underway, but once Britain had gained control of the seas, the project met the fate of all other national forestry projects. Import duty was taken off colonial timber in 1841

and from all foreign timber in 1866, and the price of home-grown timber fell so low that oak-growing, for centuries an important rural industry, became unprofitable. In 1861 there was a revival of interest, with the Navy making the largest purchases of oak of all time. Then in 1862 suddenly came the end of the wooden ship era when in Hampton Roads the ironclad Merrimac demonstrated the superiority of iron over oak.

There followed an era of stagnation in the woods, evidenced by the lack of trees planted between 1865 and 1915. With the appearance of the industrialist landowner, woods were no longer a part of a self-sufficient rural economy and came to be prized more as pleasure grounds for ornament and sport. The pheasant shoot had priority over the woodyard and the gamekeeper over the forester. Existing woodlands were treated as game coverts and amenity appendages of large rural pleasure estates. The keeper has undoubtedly helped to conserve woods and even establish new ones since 1862, but he has added little to their proper silvicultural management. Trevelyan wrote:

> During the last decades of Victoria's reign, the landlords who had planted diligently in the 18th and early 19th centuries lost interest in forestry as a trade, when the government no longer needed great oaks to build battleships and when timber poured in from Scandinavia and North America at low prices. England in 1880 could boast of finer trees than any other country, if judged by aesthetic, not by commercial standards. The forests were all gone, save a patch or two . . . Yet seen from the air, the landscape would not have appeared ill wooded. The trees were hedgerow timber scattered over the countryside, or park trees preserved for their beauty, or coverts planted for game. Estate agents were not interested in timber values and neglected to cut ivy, to thin out, and to cut and sell at the right time. The conifer was creeping in for the purpose of the new plantations, and so was the rhododendron, approved by the taste of that age. Both were exotic in most parts of the island, but both were well fitted to lodge the "kept cock pheasant, master of many a shire".

For more than 100 years there was enormous growth in population, and rapid industrialization. By 1900 nine-tenths of the national timber requirements were imported. Today Britain is still the world's greatest timber importer, but with not so much money.

Striking Contrast

In retrospect, if planting and management of the Royal Forests had been pursued consistently, there would have been sufficient oak for the Navy. In fact they rarely supplied more than a tenth of naval supplies. Despite the lack of a consistent government policy, the requirements were met by the squirarchy of England. Oak from the parks and woodlands of the landed gentry was the mainstay of the Navy. Timber was available, and sea power was maintained—although frequently by a narrow margin. Seen in this light Britain's forest policy, or lack of it, was successful.

The contrast with France is striking. There an authoritarian state intervened and, by force of example and forms of encouragement and compulsion, maintained a viable and continuing national forest policy. In Britain the state, with a Parliament controlled by landed interests, did nothing. Whereas in France private timber could be requisitioned for naval use, in England landowners could flatly refuse to sell timber to the Navy or could exact high prices, and over a century a corrupt timber monopoly developed that was finally controlled by one man and that completely cut off the supply of naval oak just prior to Trafalgar. To quote Albion, the influence of the English timber shortage may be seen in many ways, "not only in the Navy itself, but in international law, in naval architecture, and in England's foreign, colonial, commercial and forest policies as well".

One perhaps surprising effect of the 19th century hiatus was that an enormous inventory of matured timber was available in 1914 and 1939. The area of woodlands that had resulted from the Enclosure Movement of the 18th and 19th centuries was in the order of 2 million acres. Most of these acres were stocked with trees ripe for the axe. Additional were the many thousands of acres of small coppices for shelter, amenity and sport, and the hedgerows. One

hundred and eighty thousand miles of new hedges had been planted during the agricultural enclosures. By 1951, despite the inroads of two wars, there were still 73 million hedge and park trees, containing one-fifth of the remaining growing stock.

The timber shortages of World War I succeeded where earlier shortages failed. A forceful forest policy was implemented During the last 50 years a strong, highly professional forest service has implemented a large-scale plantation policy. But oak forms a negligible proportion of state planting. In the early 1960's the British Forestry Commission was planting 1,100,000 oaks annually, but this was less than 1 percent of the total. In private woodlands oak still finds a place, though most often in conifer mixtures and with somewhat doubtful economic justification.

The Problem Tree

It is important to realize that the characteristic woodlands, part of the inherent beauty of the English landscape, did not occur by happenstance. They were the consequences of planning and landscape design that rested upon a sound rural economy. Changes in economy mean changes in planning and design and changes in the landscape. This is occurring today. The hedgerow oak remains, but there is no doubt that these are being removed by hedgerow clearing, felling, and death faster than they are being replaced despite planning controls, tree-preservation orders, and the other restrictions that are accepted as necessary to control the British landscape. The mechanical hedge trimmer is not as selective as the oldtime countryman with his billhook.

Oak is now the problem tree of British forestry. The commonest and the easiest to grow, its timber is hardest to sell at a fair price to the grower. Those properties that once gave almost any piece of open-grown oak a special value now have little significance in a bulk market. The present national forest policy envisages the eclipse of broad-leaved woods as strong features in most landscapes and the domination of conifers in forests and large woods, all for the first time in recorded history.

This policy is being applied with drastic effect. Thrifty 30-year-old plantations on excellent sites have been cleared for hardwood pulp and replanted with conifers because economic evaluations indicate their unprofitability. The paradox is that while young oak promises nothing but loss, aging oak of good form is still highly profitable to keep growing on in the woodlands. Small size oak fetches only 9¢ a cubic foot, but high-quality selected sawtimber realizes $1.50 or more, while veneer quality is eagerly sought after at $3.60. The finest trees are shipped to the continent for veneer cutting.

But, despite the eclipse of oak as a commercial species, the demise of oak in the English countryside is still far off. Saxon oaks are still standing, while some of the great specimen oaks that illustrate Evelyn's *Silva* are unchanged since Restoration times. A print dated 1495 of an oak in Sussex depicts the tree as it is today. If England were abandoned because of some great natural catastrophe, the first men to return after a century would surely have to hack their way through a thicket of oak.

INTERNATIONAL TRADE IN OAK

Lumber is the oldest export from North America. Though the sages record that Lief Ericsson brought home a cargo of wood from Vinland in A.D. 1000, the first recorded exports were by the Virginia Company. In the second expedition under Captain Newport in 1609 there were eight Poles and Dutchmen skilled in erecting sawmills. It is probable that the first mill was erected at Jamestown, although the first recorded mill was at York, Maine, in 1623. Mills were operating in the Colonies 150 years before English conservatism allowed them into the home country.

Newport carried wainscot oak on his return journey. William Strachey, the first Secretary at Jamestown, wrote to London, "The oaks here, by stature and timber, may compare with any, being so tall and straight, they will bear 4 square of good timber for twenty yards long. . . ." Earliest interest was in masts and naval stores, but in the last years of Elizabeth, interest was directed toward oak also. Thus in 1615, "to relieve

the great and pitiful waste of our English woods . . . we may help ourselves out of Virginia and Sommer Islands".

So, as early as 300 years ago, England was looking to her American colonies for timber. The same year as the appearance of Evelyn's *Silva*, imports from Europe were prohibited to encourage the growing of trees in England and to develop an American timber trade. This trade offered mutual advantages. Unlike the English landowner who grew oak for profit or amenity, the colonist had to remove the trees anyway, and a market was presented to him.

But the American white oak developed a bad repute with British shipbuilders and Navy Inspection Boards. After a few trial shipments, except for small importations after the Seven Years War, the Navy made no use of colonial oak. Nevertheless American oak indirectly relieved the drain on English oak. Round logs of American oak were imported into the United Kingdom from the beginning of the 18th century. The southern colonies had the live oak, the choicest timber of all; but the indifference of the southern colonists to the timber trade made this only a minor factor in the solution of the English oak problem.

Latham *(1957)* is a principal source of information about the British timber trade, and Albion *(1925)* details the world search for naval timber during the 18th and 19th centuries.

Of the New England colonies, it has been remarked that if, as is said, the commerce of the Puritans smelled as strongly of fish as their theology smelled of brimstone, it surely rested on a foundation of pine and oak. But the Royal Dockyard prejudice was perhaps not unfounded. There is one revealing comment on colonial timber dealers, "I could wish that men of religion that bring them (knees) hither would not, when brought, cull or garble them by selling the best to private men, and when the refuse will not off, then to sell the remainder as a great service to the State at an excessive rate".

Dry Rot

Shipbuilding became a major colonial industry, and through additions to the merchant fleet, reduced the pressure on the English woodlands. But colonial ships had a poor reputation for durability. In defense of American timber, though at the expense of colonial business morality, ships built to order were often thrown together with any kind of unseasoned white oak, while the colonials sent south for live oak for their own vessels. At the outbreak of the War of Independence, colonial ships amounted to a third of the total British registry.

Also in mitigation of the bad repute of imported oak, both American and Baltic, these were often rafted, then loaded into ships' holds wet, where they became infected with dry rot before they arrived in port. Live oak was undoubtedly superior to English oak. With low, heavy branches, heavy, rapidly grown wood, and compact grain, it produced good knees and short timbers. The colonists used it for shipbuilding from 1750. But English shipwrights were not interested in the quality of oak in the forest. They knew only that imported timber was much more susceptible to dry rot by the time they were ready to use it.

During the reigns of Queen Anne and the Georges, there was considerable concern to encourage the import of American timber. Extra-naval uses reached great proportions, and imports from America exceeded those from the Baltic, the traditional source of supply. This was by no means a one-way street: there was for long a thriving return traffic to the colonies—of poachers and other forest offenders.

We all know the story of rising colonial discontent over the imperial timber policy and the enforcement of the French *mortelage* or preempting of timber for government use, which ended in the Declaration of Independence. A policy, incidentally, long rejected by the British Parliament in the home woodlands.

The Reservation of Live Oak

After Independence, the timber trade of the South expanded quickly. One of the first southern hardwood mills, and certainly the most historic, stood on St. Simons Island, Savannah, near the shipyards. Here in 1797 the sawmiller John Couper cut the frames and timbers for the famous frigate

Constitution, later a thorn in the flesh of the British in the War of 1812. But ships were built up and down the coast, and the northern shipyards continued active.

The depredations of Algerian pirates and the aggressions of the French Navy led Congress in 1784 and 1788 to authorize the President to provide warships for the protection of American merchant shipping. This led to concern for future supplies of naval timber and the first action of the Federal Government regarding timber lands. In 1799 $200,000 was appropriated for the purchase and reservation of timber or timberland suitable for the Navy. The strategic considerations that have activated concern for timber resources throughout history from the time of ancient Greece thus were instrumental in developing an interest in forest reservation on the part of the young American republic. Little was in fact done because most of the known live oak, the prime naval timber, was in Florida and Louisiana, then under Spanish and French rule. However two islands off the Georgia coast, 1,950 acres in all, were purchased.

The policy of naval expansion after the War of 1812 led to an Act of 1817 that authorized the Secretary of the Navy to select tracts of oak (and red cedar) and imposed a penalty for cutting such timber from public lands. Thus did the Republic return to a policy comparable to the strongly resisted Broad Arrow policy of colonial times.

Florida was annexed in 1819, principally for its live oak, and the President was empowered to use military force to stop the rapid destruction of the supplies of this species. In 1827 he was further authorized to take proper measures to preserve oak timbers on public lands and, further, to reserve such lands anywhere in the public domain. Additional funds were appropriated for the purchase of oak timberlands. In Florida the Government undertook experiments in transplanting and cultivating live oak. These short-lived experiments were the first attempt at Government forestry research in the United States.

A Law of 1831 superseded the 1817 Act in a further effort to protect reserved timber. This law forbade the removal of oak (and cedar or any other timber) from any lands of the United States.

Under these various Acts, small timber tracts were reserved in Georgia, Florida, Alabama, Mississippi, and Louisiana. But the depredations of timber thieves and the encroachment of settlers could not be prevented. In 1843 the Government began to dispose of these reserves and, except for a few tracts in Louisiana, completed the process after the Civil War. As in Europe the development of iron ships ended the Government's concern for ship timbers as a strategic material.

The Search for Oak

By the end of the 18th century, Britain was importing a large proportion of her consumption. A famous historian has written, "Among the regular British imports there was only one true bulk trade and one only—the timber trade". With the Napoleonic Wars and the enforcement of the Continental System, Britain was effectively cut off from her European sources of supply, and North American timber was of considerable significance. Other parts of the world also were searched for dockyard timber. Some 33,000 cubic feet of "African oak" (Iroko) were imported as early as 1823.

The world-wide search for ship timbers by the northern powers contributed to the destruction of the Italian forests. The shipwrights of Toulon had fully appreciated the oak of northern Italy. Their contemporaries in Portsmouth and Chatham recognized its value to supplement home supplies, particularly of the valuable crooked "compass" timber, after the British brought home the stores from Napoleon's dockyards at Genoa in 1814. There followed a lively rivalry for Italian oak. Diplomatic negotiations were conducted at Turin to secure the oak of Sardinia. Tuscany and the Papal States stripped their forests to build British and French warships. At the close of the wooden ship era, half the oak lying in the English dockyards was from Italy.

Other countries felt the impact of the naval rivalry. Albania, Croatia, and Hun-

gary also supplied oak. In 1899 the British arranged a loan to the Sublime Porte in return for permission to export oak from Albania. To be on the safe side they also concluded an agreement with Ali Pasha, the brigand who had carved out a virtually independent domain in the Balkans, for the sale of the Albanian oak he had previously made available to the French. The port of Parga, under British control, was exchanged for 50,000 loads (2½ million cubic feet) of naval timber as part of this deal, and its population was evacuated.

The first shipment of American oak lumber arrived in London in 1861 from Virginia. This white oak became famous in the English timber trade as "Virginia oak". Later the Central and Southern States became large suppliers, and in due course American "red oak" became established on the British market. By mid-19th century, considerable supplies of American oak were entering England. In 1865 Liverpool received 1,180,634 cubic feet of oak. In the 1880's one merchant advertised his new imports by means of a brass band playing on a wagonette placarded with "Buy my American prime cuts"—hardly according with our image of Victorian decorum but referring to the sawn and graded lumber that swept the market at the expense of the log trade.

Today, although bulk demands are a thing of the past, a market still continues for quality wood. During the immediate post-war years, world-wide hardwood sources were combed to satisfy the need of reconstruction. During the late 1940's over 350 different hardwoods figured on the British Customs Entry forms. Sawyers still have memories of the shell fragments in the German oak that was brought onto the British market at that time, until the use of mine detectors in the woodyards solved the problem. Since World War II the most notable use of oak in Britain was perhaps the reconstruction of the bombed Palace of Westminster—The House of Commons—when surveyors again combed the ancient oak woods for suitable bends and pieces for hammer-beam roof construction and wainscot panelling.

Whereas in 1938 out of a total importation of 38,663,000 cubic feet of hardwood imports into the United Kingdom, 13,-139,000 cubic feet came from the United States, in 1955 of a total of 45,260,000 cubic feet, only 1,241,000 cubic feet came from the United States. The gap has been filled by tropical hardwoods, while Japanese oak imports have risen by over 2 million cubic feet and have largely replaced the American oak that previously had a firm place in the British lumber trade.

Pointer to the Future

Today patterns are again changing, and imports are of quality veneers from France and Yugoslavia. Perhaps some have been produced from the prime oak butts exported from the English woodlands and hedgerows.

The continuing use of oak as a fine wood is perhaps a pointer to the future. It is a more comfortable note to conclude on than to contrast the two ships in which I have crossed the Atlantic: the first time, in 1958, in the Queen Mary, characterized by lavish use of wood, and the second, 10 years later, in the S. S. United States, of which it was boasted that the only wood in the entire ship was the butcher's block in the galley and the grand piano in the passenger lounge.

This account of the history of oak, and incidentally, of European forestry, has been concerned with the contrasting attitudes of France and Britain. Little reference has been made to those other countries in which *Quercus* forms a significant component of the forests and in which there have been significant contributions to its silviculture.

Nevertheless the story, even if incomplete, has several lessons that are not without significance. The French experience shows the stages of progress from early empirical and comparatively extensive methods to complex management and understanding of the crop. Developments have been in step with general social standards and political organization, with changes in silviculture and biological knowledge, and with industrial development, demands, and inventions.

A lesson is that the management of any forest must be influenced by its past, its consequent present structure, composition, and accessibility; it must suit the silvicultural and other knowledge, skills, and resources available; it must anticipate future demands on its products.

Certain stages experienced in European forest management will be omitted and methodologies will differ substantially. Nevertheless the progressive phases of European forestry provide lessons useful to us all. We will be the poorer if we ignore these lessons.

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SILVICAL CHARACTERISTICS OF THE FIVE UPLAND OAKS

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ABSTRACT. The five most important upland oaks of eastern North America are white oak (*Quercus alba*), chestnut oak (*Q. prinus*), northern red oak (*Q. rubra*), black oak (*Q. velutina*), and scarlet oak (*Q. coccinea*). Of these, white oak and northern red oak are most characteristic of northern aspects, coves, and lower slopes, while chestnut oak, black oak, and scarlet oak are typically found on upper slopes and dry ridges.

WHITE OAK
(Quercus alba L.)

WHITE OAK is the most important commercial timber species of oak in the United States and probably in the world. It ranges throughout most of the eastern United States except for northern New England and peninsular Florida. Mean annual temperature varies from 45°F. in the northern part of its range to 70°F. in east Texas and north Florida. Optimum conditions for growth are found on the western slopes of the Appalachian Mountains.

White oak grows best on northern lower slopes and in coves, but is found in wet bottom lands and on any upland aspect except extremely dry, shallow-soil ridges. Altitude is seldom a factor except in the northern parts of the range and in the higher Appalachians *(Core 1966)*.

White oak flowers appear in spring as the new leaves unfold, and the acorns ripen about October of the same year. The acorns germinate soon after they fall to the ground. This is a disadvantage because often the roots do not have time to penetrate the soil before they are killed by freezing. A heavy cover of litter is desirable. The germination capacity ranges from 75 to 95 percent. Gray squirrels are important in distributing the seeds, and a diminishing squirrel population may have adverse effects on dispersal.

Seed production is extremely variable. Some years a large number of acorns are produced (2,000 or more on a tree 24 inches in diameter); but good years do not occur with regularity, and several years may pass without any crop at all.

Seedling growth is interrupted by cold weather, but is resumed in spring. The root system has a prodigious development the first season: a seedling 3 or 4 inches high may have a taproot ¼ to ½ inch in diameter and more than a foot long.

Young white oak trees of pole size sprout vigorously from stumps or when damaged by fire. Stump sprouts in general result in trees about as good as those from seed.

White oak grows in a wide range of soils, particularly podzolic, both glaciated and unglaciated.

Growth is not particularly rapid, but is generally faster than that of hickories and almost as fast as that of black or red oak. Like many slow-growing trees, it attains a

considerable age; and individuals 600 years old have been found. Clarkson *(1964)* reported the cutting of a tree in 1913 in Tucker Couty, West Virginia, measuring 13 feet in diameter 16 feet from the base. The famous Mingo white oak, in Mingo County, West Virginia, was 9 feet 10 inches in diameter at the base and 145 feet tall when cut in 1938 *(Strausbaugh and Core 1953)*. The largest standing tree at present known in the United States is 150 feet tall and 8 feet in diameter.

White oak is intermediate in tolerance, being most tolerant in youth and becoming less tolerant as the tree becomes larger. It tends to become dominant in the stand, partly because of its tolerance and partly because of its longevity. Natural pruning is good in heavily stocked stands, but in the open the tree has a short bole and a wide-spreading crown.

Acorns of white oak were used for food by the Indians, who boiled them in water to remove tannin *(Core 1967)*.

CHESTNUT OAK
(Quercus prinus L.)

Chestnut oak has a limited geographic range as compared to the other eastern upland commercial species. It is typically a dry-site oak and does better than most other species on dry, sandy, or gravelly soils. It occurs up to elevations of 4,500 feet in the Appalachians. Maximum size, however, is attained in well-drained coves.

Chestnut oak flowers from early April to early May. Freezing temperatures at the time of flowering may greatly reduce acorn production. Good seed production may occur no more than once in a 5-year period.

The acorns mature in the first season and germinate soon after falling in September or October. Litter depth appears to be the most important single factor affecting germination and survival. Some shade on the seedbed appears to be favorable. Growth is relatively slow: in West Virginia the site index ratio for chestnut oak is 0.98, and for white oak 0.95, compared with 1.0 for northern red oak on the same site *(Trimble and Weitzman 1956)*. Chestnut oak matures normally at a height of 60 to 80 feet and a diameter of 20 to 30 inches. Maximum size is a height of 100 feet and a diameter of 7 feet.

Chestnut oak is a vigorous and prolific sprouter, and in some areas of the southern Appalachians 75 percent of all reproduction is of sprout origin. As with other oaks, however, the vigor of the sprouts decreases with the age of the stump, and decay is more frequent in sprouts from large stumps.

In tolerance chestnut oak is intermediate. In forest stands the trunk is relatively free of branches and it has excellent form on good sites. At high elevations or on poor sites the form is often gnarled and twisted.

In the mountainous region of western North Carolina chestnut oak contributes a greater volume of sawtimber than any other tree *(McCormack 1956)*. Yield is about 7,000 board feet per acre for 80-year-old trees.

The bark on old trees is very deeply and coarsely furrowed, more so than on any of the other upland species.

NORTHERN RED OAK
(Quercus rubra L.)

Northern red oak, the largest of the eastern upland oaks, extends from New Brunswick, southern Ontario, and Minnesota south to Alabama and Georgia. It is among the most important of the northern hardwoods and extends much farther north than any of the other upland oaks. Mean annual temperature varies from 40°F. in the northern part of the range to 60°F. in the southern part.

Within this range the species is most frequently found on northern and eastern aspects, in coves, and on middle and lower slopes. The best sites are characterized by fine-textured soil and a topography that favors a high water table. Soil types range from clay to loamy and from deep stone-free soil to shallow rocky soil.

The flowers develop about the time the leaves unfold in April and May. The acorn requires two seasons to mature and ripens in September and October. The trees begin to fruit when about 25 years old, and good seed crops are produced every 2 to 5 years.

The acorns germinate in the spring, after dormancy has been broken by overwintering in the leaf litter. Nearly all acorns left on top of the litter are destroyed by rodents. Available moisture is the critical factor in early survival and growth of the seedlings. Vigorous and rapid taproot development follows germination. After the taproot develops, the seedlings will withstand more drought.

In tolerance northern red oak is intermediate. It is less tolerant than white oak but more tolerant than black and scarlet oaks. Regeneration of stands from seedlings is best where the herbaceous growth is not too dense *(Carvell and Tryon 1959)*.

Northern red oak averages 70 to 90 feet in height when mature, and 2 to 3 feet in diameter. Maximum size is 160 feet in height and 8 feet in diameter.

Young northern red oak trees sprout vigorously from stumps or when killed by fire. As many as 81 percent of the stumps in a given area may sprout. Stumps as large as 22 inches in diameter develop sprouts *(Roth and Hepting 1943)*. Many second-growth stands are of sprout origin, and the resulting trunks are about as good as those from seedlings. Sprouts arising at or below ground level are less apt to decay than those arising higher. In a West Virginia study over 8,000 stems were found per acre, 20 percent being red oak *(Tryon and Carvell 1958)*.

Yields of 80-year-old red oak stands range from 2,000 cubic feet per acre to 5,300 cubic feet per acre *(Fowells 1965)*.

BLACK OAK
(Quercus velutina Lam.)

Black oak, one of the commonest of the upland oaks, occurs in most upland forest types from southern New England to northern Florida, and west to the margins of the Great Plains. It is found in the Atlantic and Gulf Coastal Plains. Mean annual temperature in this region ranges from 45°F. to 68°F., and precipitation varies from 80 inches in the southern Appalachians to less than 30 inches in Nebraska.

Black oak is usually found on upper slopes and on dry, sandy, or rocky ridges. In glaciated areas it is found on heavy clay hillsides. In the southern Appalachians it occurs up to 4,000 feet and is an important tree in the foothills. It grows on drier sites than white oak and northern red oak. In the Ozarks it tends to replace shortleaf pine in cutover areas on upper slopes and ridges. The largest trees are found in the rich soils of the lower Ohio River Valley. Black oak occurs on all aspects and slope positions, although near the limits of its range its distribution may be restricted by site.

Flowers appear in April and May, when the leaves are half-grown. The acorns mature in two seasons, ripening in September or October, dropping in November or December. Good crops of acorns may be expected every 2 or 3 years; the number of mature acorns per tree is generally higher than for other species. The trees begin to produce seeds at about 20 years of age, and optimum production is between 40 and 75 years of age.

Acorn germination is favored by a light covering of leaf litter during the winter. The primary root develops vigorously after germination, and young trees characteristically develop long taproots, which is probably the reason why they survive on dry sites.

The seedlings cannot survive under a dense canopy. For this reason black oak frequently does not occur on the better sites, where competition is greater. Because of its tolerance, black oak persists in a mixed stand only when its crown is in the upper canopy.

In the Midwest most second-growth stands are of sprout origin. Small trees sprout prolifically after cutting or after the tops have been killed by fire.

Black oak is relatively short-lived, living about 150 or 200 years. It grows more rapidly than white oak, chestnut oak, and scarlet oak, but more slowly than northern red oak *(Trimble 1960)*.

Timber yield throughout much of the range is only about 250 board feet per tree, although exceptional trees may yield 800 board feet. Maximum height is reported as 150 feet and maximum diameter as 7 feet.

SCARLET OAK
(Quercus coccinea Muenchh.)

The range of scarlet oak is smaller than that of most of the other upland oaks, but the tree is found to some extent in all States east of the Mississippi except Wisconsin and Florida. West of the Mississippi it occurs only in the Ozarks. It is frequently planted as an ornamental tree and has especially vivid autumnal coloration.

Scarlet oak is a climax tree on dry soils, commonly found on average to poor soils of ridges and upper or middle slopes. It occurs up to about 5,000 feet in the southern Appalachians.

Flowers appear in April and May, and two growing seasons are required for the acorns to mature. Seed production is irregular; however, a good crop may be expected at least once every 4 or 5 years.

A light cover of forest litter is helpful in germination of the seed. The acorns are a choice food for gray squirrels, chipmunks, and mice, which destroy many seeds. However, these rodents also help in the distribution of the seeds.

Stump sprouts are vigorous, and scarlet oak stumps appear to produce sprouts at greater ages and at larger sizes than other oaks. However, sprouts from larger stumps are often subject to butt rot *(Roth and Sleeth 1939)*.

Scarlet oak is found on a wide variety of soils, most frequently on gray-brown podzolic soils in the North and on red or yellow podzolic soils in the South.

Scarlet oak is one of the most intolerant of eastern oaks. It is seldom found in a suppressed position in a stand, indicating that it cannot survive when overtopped. It almost always exists as a dominant tree and maintains its position because of its rapid growth rate and its ability to withstand drought.

This oak is a medium-sized tree, normally maturing when 60 to 80 feet in height and 2 to 3 feet in diameter. It grows rapidly and matures early. In some areas it ranks next to yellow-poplar in rate of increase in diameter; in others it is exceeded only by yellow-poplar and red oak. Maximum size is reported as 102 feet in height and 5 feet in diameter.

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SOIL-SITE RELATIONSHIPS OF THE UPLAND OAKS

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ABSTRACT. Site quality for upland oaks can be estimated directly by using site-index curves, or indirect estimations can be made by using soil-site prediction methods. Presently available harmonized site-index curves may not be suitable for all upland oak species, or may not be suitable throughout their range. New stem-analysis data show that different species of oak have different patterns of height growth; for older ages these patterns are markedly different from patterns predicted by harmonized site-index curves. Soil-site studies for upland oaks are reviewed, and suggestions are made for coordinating these results with soil surveys for forested lands.

INTENSIVE MANAGEMENT of forest land for upland oaks requires precise information about oak site quality. This knowledge is needed so that we can estimate quantity and quality of wood products from specific portions of our forest land. Site quality information also aids us in determining what species of oak to grow and what products to favor on lands of differing productivity. Finally, accurate identification of site quality will better enable us to concentrate intensive management on productive forest lands that are capable of producing large yields of high-grade timber.

SITE-INDEX CURVES

The most widely accepted method for estimating site quality in the United States is direct estimation of site index. Height and age measurements from dominant and codominant trees are used with site-index curves to estimate how tall trees will be at an index age—50 years for upland oaks. Estimated site index is then related to yield tables to estimate growth and yield at various stand ages. The site-index method can easily be used when suitable forest trees are available for the required height and age measurements.

However, suitable trees may be lacking in many upland oak forests because stands may be uneven-aged, poorly stocked, too young, damaged by fire or heavy grazing; or the forests may have been subjected to a variety of past cutting. Satisfactory site-index measurements can be taken only from dominant and codominant trees that have been free-growing and uninjured throughout their lives. Such trees are most commonly found in even-aged oak stands that have not been disturbed by past cutting.

Three sets of harmonized site-index curves are available for upland oaks *(Schnur 1937, Gevorkiantz 1957, Olson 1959)*. These curves show different patterns of height growth when they are compared at the same level of site index (fig. 1); differences are particularly great for older stands. For example, at 100 years of age and at site index 60, the Olson site curves predict that

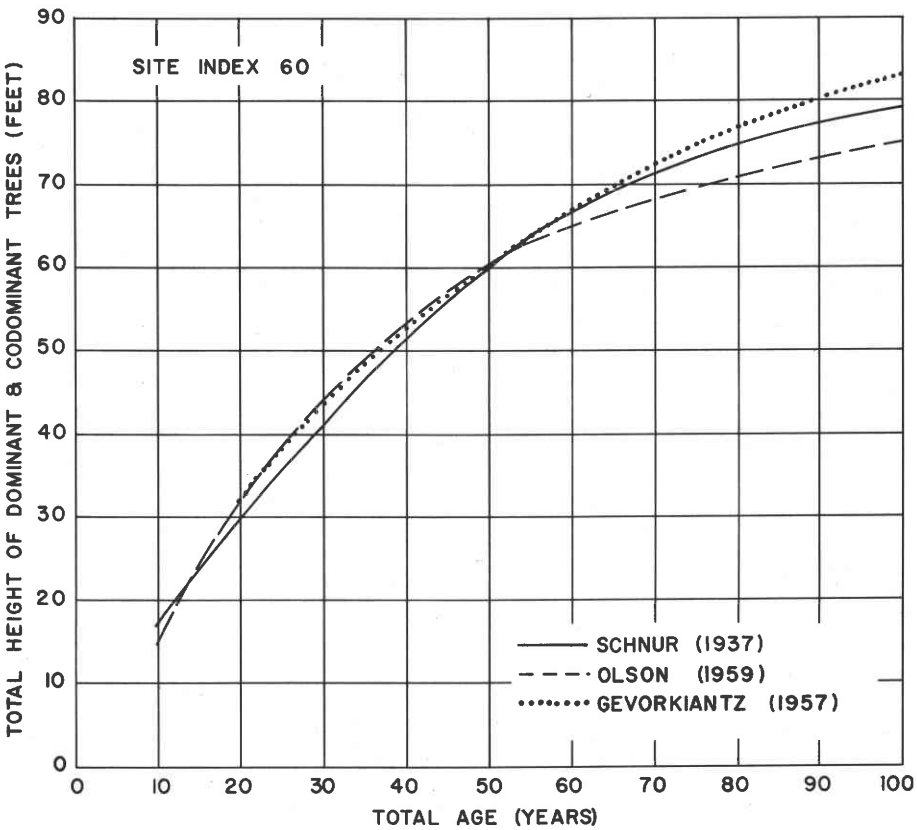
trees will be 75 feet tall, the Schnur curves predict 79 feet, and the Gevorkiantz curves predict 83 feet. Accordingly, when site index is estimated in older-aged stands, these different height-growth patterns result in the lowest site-index values (estimated height at age 50 years) when using the Gevorkiantz curves, intermediate values with the Schnur curves, and the highest values with the Olson curves.

Which set of site-index curves should a forester use for estimating oak site index? Do trees on all sites follow the same pattern of height growth, or do trees on good sites follow a height-growth pattern different from that for trees on poor sites? Are the regionwide oak harmonized curves applicable to all species, all areas, all levels of site, and all soils? Or do we need separate polymorphic site curves for each species of oak and for local portions of the oak region?

We cannot adequately answer these questions now because we do not have sufficient knowledge about height-growth patterns for different oak species growing in different portions of the upland oak region. Until we obtain this specific knowledge, site-index estimates from existing site-index curves can be viewed only as general approximations of oak site quality. Accordingly, when we are uncertain about the applicability of regionwide harmonized site-index curves, we should measure trees as close as possible to 50 years of age. Trees ranging from 35 to 65 years are probably acceptable *(Carmean 1970a)*.

We are faced with a complex problem when we try to precisely describe the vary-

Figure 1.—Harmonized site-index curves for upland oaks show differing height-growth patterns when compared at the same level of site index. Differences are particularly great at older ages.



ing patterns of height growth for different oak species in different areas growing on differing levels of site quality. Answers to this complex problem require mensurational methods more precise than the methods used for constructing harmonized site-index curves. This more precise method is stem analysis or tree sectioning, a procedure that has long been used for diameter, volume, and height-growth studies. The stem-analysis method has been used widely in recent years for constructing site-index curves for many tree species *(Carmean 1970b)*. However, new oak site-index curves based on stem analyses have not yet been published.

Stem analyses for upland oak site-index curves are now under way in the Arkansas and Missouri Ozarks, in eastern Tennessee, and in the southern Appalachians. And considerable stem-analysis data are now available for four species of upland oaks in the Central States. Site-index curves have been prepared for these oak species *(Carmean 1971)*, and some of the findings are given here.

FOR UPLAND OAKS

Briefly, 559 dominant and codominant upland oaks growing on 204 plots in the Central States were felled and sectioned. Ring counts were made at regular intervals on the boles, from the stump to the growing tip of each tree. A wide range of site index was observed (site index 18 to 106), and trees as old as 129 years were sectioned. All plots were located in even-aged stands found in the unglaciated portions of Ohio, Kentucky, Indiana, Illinois, and Missouri. These data were used to compute separate sets of polymorphic site-index curves for black, white, scarlet, and chestnut oaks.

Our new site-index curves reveal definite differences in height-growth patterns for each of the four species of upland oaks (fig. 2). Fairly similar height growth is evident for all species until about 60 years of age, but then the height-growth curves diverge. White oak has relatively slow height growth in early years, but this growth rate apparently is maintained well past 100 years of age. In contrast, black and scarlet oaks initially have more rapid height growth than white oak; however, after 60 years these species show a much more pronounced slowing of height growth. Chestnut oak has a pattern of height growth intermediate between white oak and that of black and scarlet oak. We have found that all these oaks maintain more rapid height growth in later years than predicted by the Schnur *(1937)* and Olson *(1959)* site-index curves. However, our curves for black and scarlet oaks are similar to Gevorkiantz's *(1957)* site curves for red oak in the Lake States.

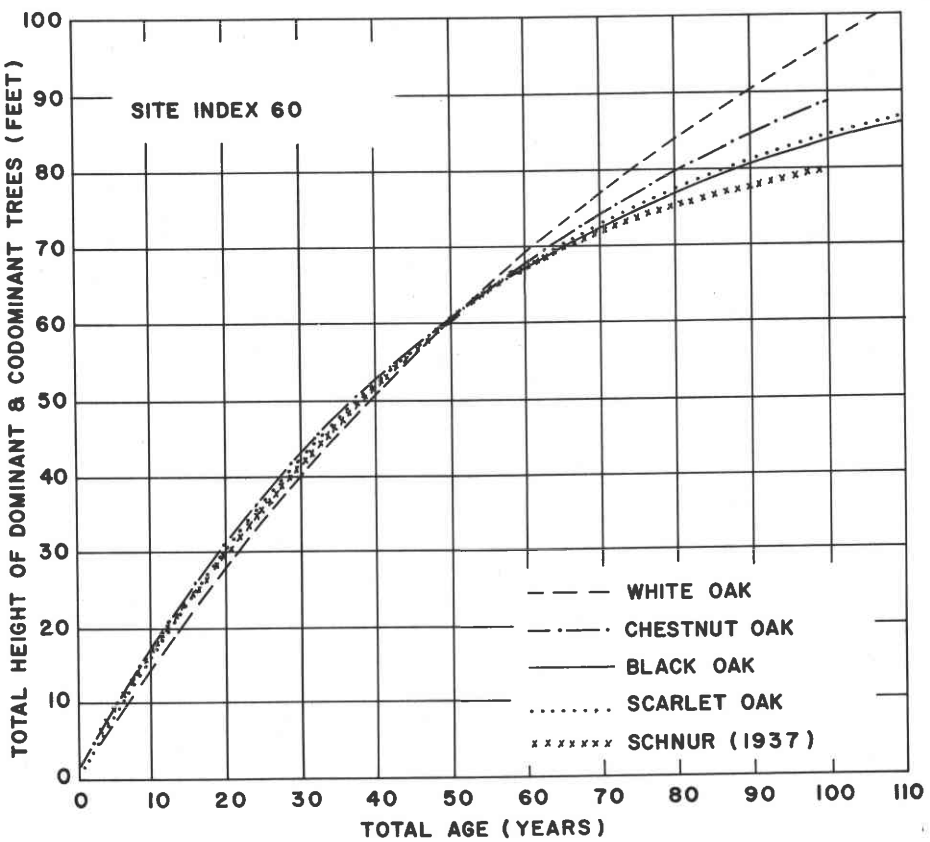
These large differences in tree height-growth patterns (fig. 2) mean that oak site index measured in older stands also will show large differences, depending upon which site-index curve is used. For example, if we find that dominant and codominant trees are 79 feet tall at 100 years of age, then the Schnur curves predict that their height at 50 years (site index) was 60 feet. However, if these trees are white oaks, then figure 2 shows that their growth pattern is much more linear than the pattern predicted by the Schnur curves. Consequently, if white oaks average 79 feet tall at 100 years, than at 50 years their height was much less than the 60 feet predicted by the Schnur curves. If we assume that their height growth will be proportional to the white oak curve in figure 2, then dominant white oaks 79 feet tall at 100 years were probably only 49 feet tall at 50 years instead of 60 feet tall. Likewise, for trees 79 feet tall at 100 years, the curves of figure 2 indicate that chestnut oak was 54 feet, scarlet oak 56 feet, and black oak 57 feet tall at 50 years of age. Obviously the Schnur and Olson curves will overestimate site index when used in older stands, and the amount of this overestimation is different depending upon tree age and upon the species of oak involved.

Site-index estimation is a vital first step in estimating future growth and yield. But our studies show that, if we measure site index in young stands, then estimates of future height growth, and future growth and yield, will differ depending upon the site-index curves we use. For example, if we measure dominant and codominant tree heights in oak stands exactly 50 years of age, then their present height is defined as site index.

But what about height and volume projections for the future? Schnur's site-index curves predict that these trees will be 79 feet tall at 100 years of age regardless of species (fig. 2). However, our studies predict that if trees are 60 feet tall at 50 years of age, then black oak will be 83 feet, scarlet oak 84 feet, chestnut oak 88 feet, and white oak 96 feet tall at 100 years of age. Obviously, tall trees also will produce more volume because tree height, together with tree diameter and number of trees, determines the volume of forest stands. Accordingly, even though white and black oaks may be the same height at 50 years (same site index), at 100 years of age we can expect stands containing mostly white oak to have taller trees and more volume than stands containing mostly black oak.

Of course, when several species of oak are growing together on the same plot, their average height at 50 years will vary depending upon species of oak. We can assume for discussion purposes that dominant and codominant white oaks will be perhaps 5 feet shorter than black oaks at 50 years of age—that is, black oak will indicate site index 60 and white oak site index 55. Probably the site index 60 black oak will grow as shown in figure 2, and the site index 55 white oak will grow proportional to the pattern shown for white oak in figure 2. Accordingly, even though white oak is 5 feet shorter than black oak at 50 years, we estimate that dominants and codominants of both species will be 75 feet tall at 77 years. Thereafter, the white oak will surpass the black oak until at 100 years we

Figure 2.—Tree height-growth patterns for four species of upland oaks reveal decided differences in growth for older ages. Also shown is the Schnur *(1937)* site-index curve for upland oaks.



estimate the white oaks will average 88 feet and black oaks 83 feet in total height.

Our results indicate that we must carefully evaluate the accuracy and applicability of all regionwide harmonized site-index curves. More intensive management of the future will require more precise evaluations of land productivity for forest trees than has been possible by using older generalized site-index curves. In many cases we may find that a single set of site-index curves cannot adequately express the different growth patterns for tree species that have wide geographical ranges, or that grow on land having a wide range of climate, soil, and topography.

SPECIES COMPARISON

Many even-aged oak stands suitable for site-index measurements may not contain the particular oak species, or other hardwood species, for which site-index estimates are desired. Dominant and codominant trees of several oak species may be present, but no usable trees of the particular desired species may occur. For such stands we can estimate site index by using the tree species that are actually present. Then species-comparison graphs can be used to convert site index of the measured trees to site index of other desired tree species. Species-comparison graphs and site-index ratios have been published for upland oaks and other hardwoods *(Doolittle 1958, Nelson and Beaufait 1956, Olson and Della-Bianca 1959, Trimble and Weitzman 1956)*. These studies usually indicate that, at 50 years of age, scarlet and northern red oaks will be the tallest trees, black and chestnut oaks will be intermediate in height, and white oaks will be the shortest trees.

Species-comparison graphs are very useful for extending the application of direct site-index measurements. However, we should bear in mind that comparisons are based only on tree height at one point in time—namely, 50 years of age. But if tree heights are only compared at 50 years, then we might conclude that scarlet oaks or black oaks are faster growing and more productive than white oaks. On the other hand, if the index age for oaks was 100 years, as for certain western trees, then species-comparison graphs would show that white oak was the tallest tree, and consequently, white oak might be judged as the most productive species.

These differences in patterns for tree height growth indicate that we also should compare heights of oaks both before and after the index age of 50 years. In addition, comparisons should be made for both volume and value of yield throughout the lifetime of each species of tree considered for management. Such comparisons might better help us select the species of tree, and most valued product, for management at each level of site quality.

For example, these broader comparisons might reveal that scarlet and black oaks grow faster and produce greater volumes than white oak in early years. Thus these species might be preferable for short pulpwood rotations on poorer sites not capable of producing large trees of veneer and high-quality sawlogs. On the other hand, white oak apparently surpasses the growth of scarlet and black oaks in later years, and thus seems able to eventually attain a larger size and greater volume than other oaks. Accordingly, this more rapid later growth may mean that white oak is better suited for long rotations on better sites where quality veneer and sawlogs are the most desirable products.

SOIL-SITE RELATIONSHIPS

Measurements of site index from standing trees are very satisfactory whenever suitable stands and trees are present for the required tree height and age measurements. But the land may be devoid of trees; or trees may have been injured by fire or heavy grazing; stands may be very young; they may be uneven-aged; or indiscriminate cutting may have removed the free-growing dominant and codominant trees needed for direct site-index measurements. Therefore soil-site methods of site-quality estimation are needed that are applicable to all forest land regardless of the composition or condition of existing vegetal cover.

Much information has been accumulated about the relationships between forest site

quality and features of soil, topography, and climate *(Coile 1952, Ralston 1964)*. A recent article also has summarized the various soil-site studies for eastern hardwoods *(Carmean 1970a)*. This article lists a total of 19 separate soil-site studies for upland oaks, so this summarization will not be repeated here.

Most soil-site studies describe the relationship between site index and associated features of soil, topography, and climate. These studies not only identify the important features of site, but also include regression coefficients that express the magnitude of site change associated with each of the significant features of site. Site features pinpointed by these studies are then used to compute site-prediction tables for the field estimation of site quality. These site-prediction tables, developed for a particular area and tree species, provide a means for estimating site quality of all forest lands regardless of the composition or condition of existing vegetal cover.

The review of eastern hardwood soil-site studies *(Carmean 1970a)* reveals certain general trends about the soil and topographic features usually associated with changes in oak site quality. Soil conditions most important are soil depth, soil texture and stone content, and soil drainage—that is, those soil properties ". . . which influence the quality and quantity of growing space for tree roots" *(Coile 1952)*. In general, oak site quality improves as soil depth increases, and trees seem to be most affected by depth changes in the surface soil layers where the majority of tree roots are concentrated. Usually medium-texture soils are the best sites, and site quality decreases for both coarse-texture and for fine-texture soils. Site quality usually decreases as stone content increases, and sometimes as drainage becomes poorer.

Topographic features most important are slope position, aspect, and slope steepness. The best sites usually are found on lower slopes, on north and east aspects, and on gentle concave-shaped slopes. Poorer sites usually are found on narrow ridges, on upper slopes, on south and west aspects, and on steep convex-shaped slopes. These topographic features apparently are closely related to microclimate, soil, and moisture conditions that are important for tree growth.

Even though we can generalize about soil and topographic features related to oak site quality, we find that soil-site studies show considerable variation in site features found to be important. Features important in one area may be unimportant in another. Sometimes a feature may show positive trends in one area and a negative correlation with site quality in another area. Reasons for these variable results may include growth differences between oak species, differences in study areas, and different methods used in statistical analyses *(Carmean 1970a)*.

Because of these differing results between areas we should exercise caution in attempting to apply results developed in one region to a different region. Soil-site prediction methods are applicable only to the particular area studied and, further, to the particular soil and topographic conditions observed within the study area. For example, results obtained for upland oaks in Ohio should not be applied in other states where soil, topography, and climate are different. Likewise, within a particular study area, results for upland soils should not be applied to bottomland soils or to other soil conditions not included in the original site study. Oak soil-site correlations developed from studies of undisturbed forest soils may not be applicable to oaks planted on soils disturbed by agriculture or heavy grazing.

Even so, when nearby regions are similar in soil, topography, and climate, then results from one region probably can be safely applied to the other region. However, results should be applied with caution until trials are made to test the applicability of these results. Of course, when regions have contrasting differences in soil, topography, and climate, then it is unlikely that results from one region can be applied to another.

The fairly large number of soil-site studies for upland oaks *(Carmean 1970a)* may appear impressive at first glance. However, bear in mind that upland oaks cover a very large area that is extremely diverse in soil, topography, and climate. Furthermore, upland oaks include many species

that frequently respond in different ways to these varying conditions of soil, topography, and climate. Accordingly, it soon becomes apparent that large gaps in our knowledge exist for many important areas and for many important species of upland oak. For example, the Northeast, the Lake States, and the glaciated portions of the Midwest have received relatively little study.

Site evaluation based upon soil-site methods permits us to estimate site quality only for the local spot in the landscape where we may happen to measure the significant features of soil, topography, and climate. Thus site evaluation still is a point observation comparable to point observations of site index using trees themselves. Still to be resolved is the problem of abstracting these point observations into an area classification of the landscape. Here is where forest managers can best use the skill and knowledge possessed by soil surveyors. Closer coordination between soil-site research and soil survey can provide land-classification knowledge and techniques useful in forest land management. Research can pinpoint the features of soil and topography important in classifying site quality, and soil surveyors can then incorporate this knowledge into soil surveys to obtain more useful inventories of forest lands.

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THE SUPPLY AND DEMAND SITUATION FOR OAK TIMBER

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ABSTRACT. Twenty oak species in the eastern United States account for one-third of the hardwood sawtimber volume and almost 10 percent of both hardwood and softwood growing-stock volume. The oak-hickory and oak-pine forest types occupy about 38 percent of the forest land in the eastern United States. Oak timber volume is increasing. Annual growth exceeds annual removals by about 20 percent. In the next 30 years large increases in demand for oak timber are probable; and the better quality oak timber, particularly in the South, will probably be increasingly scarce.

THE OAKS are the most important hardwood trees in the North Temperate Zone. Fifty-eight different species reach tree size in the United States, and 20 of these are important timber trees in the Eastern States. Collectively the oaks account for about one-third of the hardwood sawtimber volume and almost 10 percent of the total volume of both hardwood and softwood growing stock in the United States.

(Oak growing stock is composed of live merchantable sawtimber and poletimber trees measured from the stump to a minimum 4-inch top diameter outside the bark of the central stem. Sawtimber trees are live merchantable trees 11.0 inches d.b.h. and larger. Poletimber trees are live merchantable trees 5.0 to 10.9 inches d.b.h.)

About 90 percent of the oak volume is found in the eastern United States. However, there are some oaks in Oregon, California, and Washington that attain commercial timber size. And some eastern oaks extend their range into southern Canada.

The oaks may be classified in a number of ways. In this symposium, most of the discussion will be concerned with five eastern upland oaks—white, chestnut, northern red, scarlet, and black—that are important in the Appalachian area.

My discussion is based on oak resource statistics collected by the Forest Survey (USDA Forest Service 1958 and 1965). Nationwide data also have been compiled on the 1968 situation, but they have not been published; Where applicable, they have been used. For the most part, Forest Survey statistics do not provide specific data on the five symposium species; so most of my discussion will be about the following four major eastern oak groups:

1. The select white oak group, of which white oak is the predominant species but which includes also chinkapin, bur, durand, swamp chestnut, and swamp white oaks.
2. The other white oak group, which includes chestnut oak and post, overcup, and live oaks.

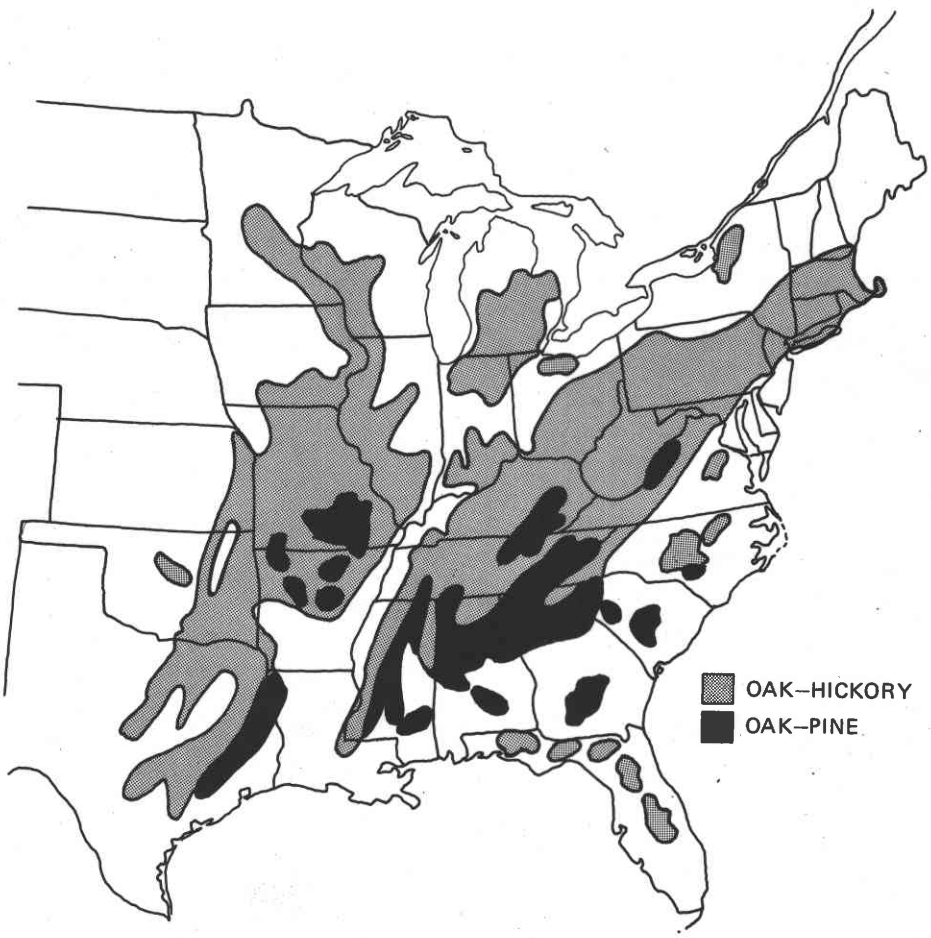
3. The select red oak group, of which northern red is the predominant species, but which also includes cherry bark and shumard oaks.
4. The other red oak group, which includes black and scarlet oaks as major components, but also includes pin, southern red, laurel, nuttall, water, and willow oaks.

OAK COVER TYPES

The five oaks about which this symposium is concerned—along with chinkapin, post, and bur oaks—usually occur on the upland sites and for the most part in the oak-hickory and oak-pine types. As defined in the national Forest Survey, the oak-hickory forests are those in which upland oak, or hickory, singly or in combination, comprise a plurality of the stocking except where pines comprise 25 to 50 percent, in which case the stand is classified as oak-pine (fig. 1). The other oak species are found mostly on the wetter or bottomland sites along with associated lowland species.

In the eastern United States, oak-hickory forests dominate the forest landscape, covering about 117 million acres. Along with oak-pine, which covers 27 million acres, they account for about 38 percent of the forest land area in the eastern United States.

Figure 1.—The oak-hickory and oak-pine forest types occupy 38 percent of the forest land in the eastern United States, 1963.



Oak types are important in all the regions established by the Forest Survey in the eastern United States (fig. 2). The Central States region, with 30 million acres, has the greatest area of oak-hickory and oak-pine forests. However, the four southern regions contain about 60 percent of all land in these types.

On a state basis, ten states contain two-thirds of the oak-hickory and oak-pine type acreage:

State	*Million Acres*
Missouri	12.0
Tennessee	10.7
Virginia	10.2
Arkansas	10.0
Alabama	9.9
Pennsylvania	8.8
Kentucky	8.0
North Carolina	7.8
Georgia	7.7
West Virginia	7.6

Missouri, Tennessee, and Kentucky have more than three-fourths of their forest land in the oak-hickory or oak-pine types; while West Virginia, Virginia, and Pennsylvania have from one-half to three-quarters of their forest land in these types. A number of states with less forest area also have more than 50 percent of their forest area in the oak-hickory or oak-pine types. They include Oklahoma, Ohio, Indiana, Illinois, Maryland, Connecticut, Kansas, and Rhode Island.

TIMBER VOLUME

The total oak volume is about 78 billion cubic feet. Of this, some 15 percent is in rough and rotten trees that are not now considered merchantable. The growing-stock volume in 1968 exceeded 66 billion cubic feet. Pennsylvania had more volume

Figure 2.—Million acres of oak-hickory and oak-pine timber types, by geographic regions, 1963.

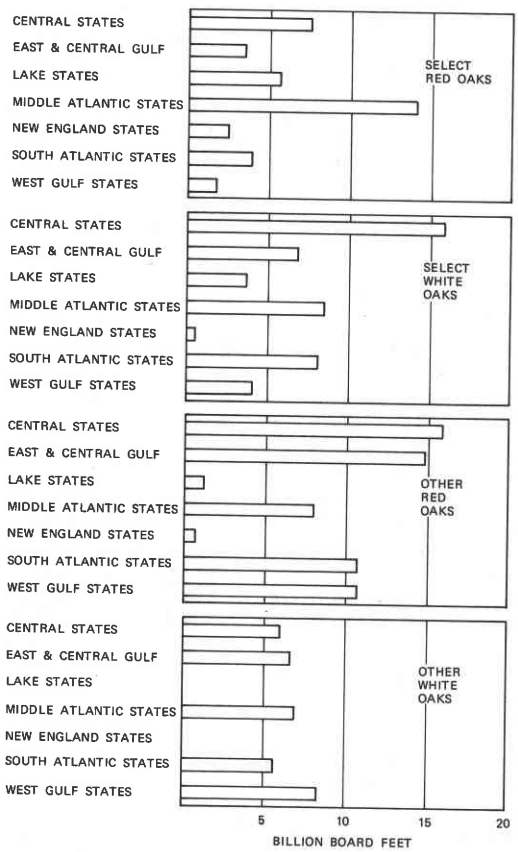


than any other state (7½ billion cubic feet). But Virginia, West Virginia, North Carolina, Kentucky, Missouri, and Arkansas all had over 3 billion cubic feet each.

The oak sawtimber volume in the United States in 1968 was approximately 180 billion board feet. States that had more than 10 billion board feet each included Kentucky, Pennsylvania, Virginia, and West Virginia. These four—along with Arkansas, Georgia, Louisiana, Missouri, North Carolina, and Tennessee—accounted for almost two-thirds of the oak sawtimber volume in the United States. The select white oaks accounted for 26 percent of the oak volume, other white oaks 18 percent, the select red oaks 22 percent, and the other red oaks 34 percent.

Almost 40 percent of the select red oaks are found in the Middle Atlantic States. One-third of the select white oak volume occurs in the Central States, and another one-third in the Middle and South Atlantic States. The Central and Gulf States contain more than two-thirds of the other red oak volume. The other white oaks are not present in the Lake States and New England, but are about equally distributed throughout the other regions (fig. 3).

Figure 3.—Oak sawtimber volume, by regions and species groups, 1963.



TIMBER QUALITY

Of the growing-stock volume, 42 percent is of poletimber size (5.0 to 11.0 inches d.b.h.), and about 28 percent is found in small sawtimber (11.0 to 15.0 inches d.b.h.) trees.

Thus only about 30 percent of the oak volume is in trees of a size having some volume suitable for high-value products such as veneer, barrel staves, and the better grades of factory lumber.

The quality of the sawtimber resource may be evaluated by quality classes based on factory-lumber log grade *(Ostrander 1965)*. In 1963 about 10 percent of the oak sawtimber volume was in factory-lumber grade-one logs. These are logs from which two-thirds or more of the lumber is usually Number 1 Common or Better. Another 16 percent was in factory-grade 2 quality logs from which normally about 40 percent of the lumber is Number 1 Common or Better. Approximately 48 percent of the volume was in the lowest grade of factory-lumber logs, while 26 percent was suitable only for tie and timber production. The better quality oak timber was most plentiful in the Middle Atlantic States:

Region	*Volume in log grades 1 & 2 (million bd. ft.)*
Middle Atlantic States	13
East & Central Gulf States	8
Lake & Central States	8
South Atlantic States	7
West Gulf States	7
New England States	1

CHANGES IN VOLUMES

The last three nationwide surveys have all indicated increases in oak timber volumes:

	Oak growing stock (billion cu. ft.)	*Oak sawtimber (billion bd. ft)*
1953	53	146
1963	61	163
1968	66	180

Between 1952 and 1963, oak sawtimber volume increased about 12 percent. And between 1963 and 1968 the increase was about 10 percent.

However, this general volume increase was concentrated in the smaller diameter-class trees. The volume in trees over 19 inches d.b.h. has changed little between 1952 and 1968. Oak sawtimber volume is increasing more rapidly in the North than in the South. In the North, between 1953 and 1963, oak sawtimber volume increased 16 percent, while in the South it increased only 7 percent.

GROWTH AND REMOVALS

In 1968, the growth on the growing stock amounted to about 2.4 billion cubic feet. Growth thus was at about a 4-percent rate. And it exceeded removals by 50 percent.

In the sawtimber size classes, annual growth was at a 3.5-percent rate; it amounted to about 6.4 billion board feet. It exceeded removals by 20 percent. But this growth-removal relationship was not uniform throughout the Nation (fig. 4).

In the South, oak sawtimber growth was only about 7 percent greater than removals. In the North, the sawtimber growth exceeded sawtimber removals by almost 50 percent.

Forest lands in different kinds of ownership also have different rates of removals. An increasing acreage of the privately owned nonindustrial forest land is being held for recreation, speculation, or other nontimber objectives. Cutting of timber from such lands is limited. Forest land in these kinds of ownerships is concentrated around large metropolitan areas in the northern United States.

Historically, cutting on forest-industry owned lands has been heavier than on other lands. For example, in 1962, hardwood sawtimber removal from forest-industry lands was greater than the growth. In all other kinds of ownerships growth exceeded removals by substantial margins.

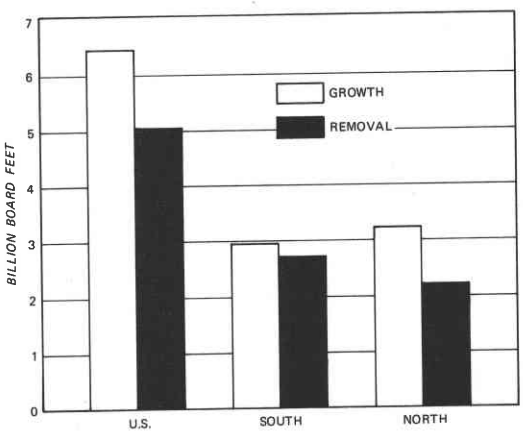
This ownership pattern helps to explain the heavier cutting taking place in the South, where timber industry controls 19 percent of the land. In contrast, in the North, only about 8 percent of the forest land is owned by forest industry.

More than half of the oak timber harvested goes into lumber and other sawed materials for eventual use in such products as flooring, dimension stock, furniture, pallets, cross ties, and cooperage. Almost 20 percent goes into the production of pulp and paper products. The remainder is distributed among many uses, including posts, mine timbers, veneer, fuelwood, and chemical wood.

TIMBER DEMAND

Now look at the demand side of the resource situation and consider the future

Figure 4.—Oak sawtimber growth-removal relationships, by regions, 1968.



supply-demand or growth-removal relationships. Two major determinants of demand are population and the gross national product (GNP).

Population growth from 1920 to 1968 and projections of population growth by the Bureau of the Census indicate that the population in the United States in 2000 will be somewhere near 280 million people—a 40 percent increase over the present population.

All projections of the gross national product likewise indicate that the output of goods and services in the decades ahead will increase tremendously, probably doubling by 2000. Projections of disposable personal income follow the same general trends. Residential construction is expected to grow rapidly.

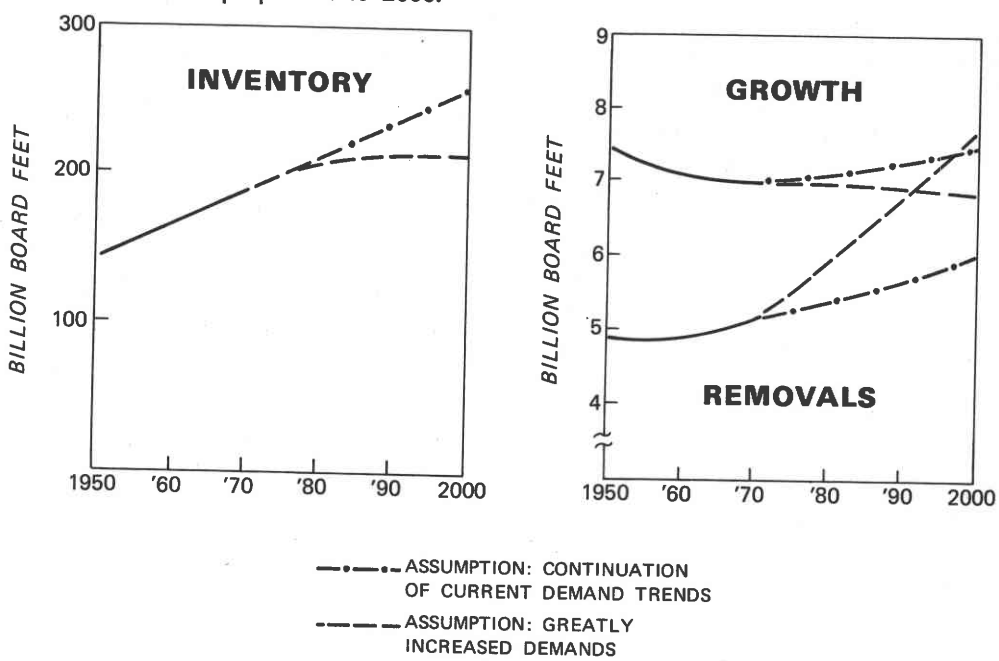
The projected increases in population, income, and housing indicate a large increase in demand for oak timber. However, increase in the demand for oak will also depend on many other factors such as prices, technological changes within the oak using and competing industries, and institutional changes.

But assuming that population and economic growth will rise about as described above, and that the price and technological trends will not differ significantly from those of competing materials, projected demand for hardwood sawtimber should rise about 40 percent by 2000 *(Hair 1970)*. About three-fifths of the demand will be for railroad ties, pallets, containers, and flooring. These lumber products can be manufactured economically from relatively small or low-quality logs, but most of the remaining demand will be for lumber for use in cabinets, paneling, furniture, and other products where quality and surface appearances are important considerations.

The projected demand for pulpwood from oak timber is expected to almost triple by 2000. This demand can be met from the smaller sizes of oak timber, in which growth substantially exceeds removals. However, should large acreages of the oak timber types be withheld from commercial timber production, supply difficulties could develop in some areas.

On the basis of the assumptions just mentioned and on the assumption that cur-

Figure 5.—Oak sawtimber inventory, growth, and removals, 1950 to 1968 and projections to 2000.



rent levels of management for oak timber will continue, projections of possible oak supply-demand relationships were developed from data presented in *Timber Trends in the United States* for all hardwoods *(USDA Forest Service 1965)*.

Under one assumption, current trends in demand for oak timber are projected to continue. Under the other, demands are projected to rise sharply to reflect major population increases, a doubling of the gross national product, price trends of oak timber products not differing significantly from competing product prices, and some substitution of oak and other hardwoods for softwood timber products.

These 30-year projections (fig. 5) indicate that oak sawtimber volume probably will continue to increase at least for the next 20 years. After that, depending on the rate of removals, the oak timber resources may increase, stabilize, or even decrease.

The assumptions used in making any projection may not hold true for long in this fast-changing world. Therefore projections are probably more useful in evaluating the situation over the next decade or two

In the long run, it may be desirable to provide substantial increases in oak sawtimber volume. These could be obtained by improved management practices. Management should be directed toward providing increased supplies of the larger diameter and better quality oak trees, because it is this kind of material that is currently in strong demand and in which future shortages will probably develop most rapidly.

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SILVICULTURAL METHODS FOR REGENERATING OAKS

by F. BRYAN CLARK *and* RICHARD F. WATT, *respectively Assistant Director and Research Plant Physiologist, North Central Forest Experiment Station, Forest Service, USDA, St. Paul, Minn., and Columbia, Mo.*

ABSTRACT. Advance reproduction is the key to forming the new oak stand. However, the size or strength of the advance stems is just as important as number. Most oak stands approaching maturity have enough advance reproduction, but many do not. In such cases, harvest cuttings must be delayed and overstory densities regulated to favor the establishment and development of new oaks in the understory.

TWO BASIC PRINCIPLES should be understood when we discuss natural regeneration of upland oak stands:

1. The new stand will contain oak in proportion to the advance oak reproduction on the area before the harvest cut.
2. Advance oak reproduction must have a well-established root system in order to compete successfully with other woody vegetation.

Although many details for obtaining oak reproduction are not clear, these two basic principles are supported by research and experience *(Clark 1970)*. A number of experimental cuttings – including seedtree, shelterwood, and clearcutting – have failed to establish significant amounts of oak where newly established seedlings were relied on to regenerate the stand.

Many oak stands at or near harvest age contain enough advance oak to form a new stand. But there are also areas that do not contain adequate reproduction. Parts of Minnesota, Wisconsin, Michigan, Missouri, Indiana, and New Jersey have been cited as problem areas. Concern about the inadequacy of advance reproduction is mounting. There is good reason to believe that a lack of oak reproduction may be related to less fire, less grazing, denser overstories, and successional trends toward more mesic species.

With the advent of even-aged management, our mistakes will catch up with us quickly. However, we are convinced that some of this concern is premature and that more time is needed to evaluate final results *(Sander and Clark, in press)*. Before silvicultural treatments to reproduce oak can be prescribed, we must first understand how silvical and environmental factors relate to establishment and growth of various types of oak reproduction.

SILVICAL CHARACTERISTICS

Dependence upon advance reproduction is possible because oak seedlings and saplings are moderately tolerant. Of the five important commercial species, white oak is the most tolerant; chestnut, northern red,

and black oaks are intermediate; and scarlet oak is least tolerant. However, the ability of oak seedlings to survive in the understory must not be interpreted to mean that oak can be grown in all-aged stands like sugar maple. Oak grows best in full sunlight, and oak silviculture should be even-aged. During regeneration, harvest cutting must provide full sunlight for oak to compete successfully with its associates regardless of area size.

Oak seed crops are periodic. Black oak is the most consistent, producing some seed every year and good crops every 2 to 3 years *(Fowells 1965)*. The other four species generally have a high probability of producing a good crop every 4 or 5 years. Chestnut and white oaks are said to be some what more irregular than species in the red oak group. A large proportion of the crop is often rendered useless by insect infestation; birds and mammals utilize much of the crop for food. Even so, some seed dispersal is due to animals. Despite heavy losses, enough viable seeds are produced in good seed years to establish seedlings in most stands more than 50 years old. The problem is to maintain and strengthen this reproduction so it may win the competitive struggle with other plants and form the new stand.

In most stands, seedbed conditions will not inhibit the establishment of oak. One inch of litter seems desirable for establishing seedlings *(Minckler and Jensen 1959)*, but thicker layers are not highly detrimental. Disturbing the surface by disking increased the seedling catch, but the increase did not warrant the additional cost *(Scholz 1955)*.

It is important to define the different types of advance reproduction and the roles they play in oak silviculture. First, seedlings are produced from acorns. Second, seedling sprouts arise from stumps less than 2 inches in diameter at the ground line. Third, stools or grubs are seedling sprouts that have died back several times over a period of years, producing a large surface callous and a well-developed root system. Liming and Johnston *(1944)* explained how this type of reproduction gradually builds up to a point where it is strong enough to compete in the new stand when the overstory is removed. Fourth, stump sprouts originate from stumps 2 inches or more in diameter.

Seedlings, stool sprouts, and stump sprouts grow at different rates (fig. 1). Stump sprouts are by far the fastest growers, followed closely by stool sprouts, and seedlings are a poor third.

Newly established seedlings obviously cannot grow fast enough to form a part of the new stand. A bumper catch of 1-year-old chestnut oaks released by clearcutting in southern Indiana in 1929 failed to comprise a significant part of the new stand 10

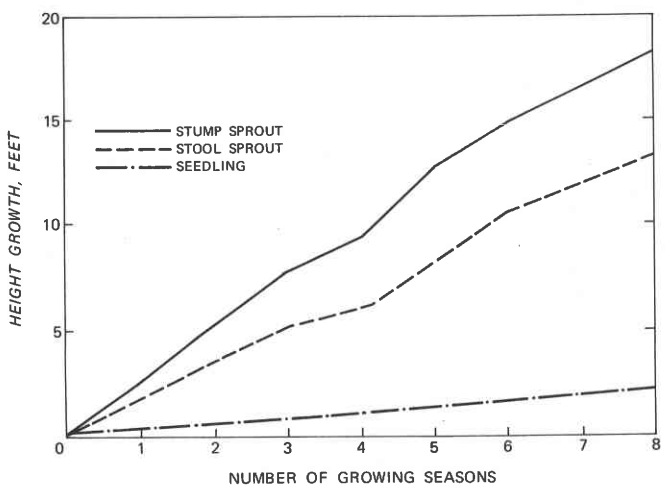


Figure 1.—Height growth of white oak stump sprouts, stool sprouts, and seedlings after release.

years later *(Kuenzel and McGuire 1942)*. After 36 years, the overstory was composed primarily of oak stump sprouts: the few surviving chestnut oak seedlings were only 5 feet tall.

Advance reproduction must be sturdy to have a good chance of becoming a part of the new stand (fig. 2). An Ohio-Kentucky study showed that unless the stem is at least ½ inch in diameter at ground level, or is at least 4 feet tall, it will probably be outgrown by competitors. On the best oak sites, even larger reproduction would be desirable for competing with the dense, vigorous brush. Much advance oak reproduction is either broken off during logging or dies back to the ground after the sudden exposure.

Figure 2.—The white oak held at left was small and spindly when the clearcutting was made 12 years ago. In contrast, the red oak at right was dominant in the understory before cutting.



ECOLOGICAL FACTORS

Oak types are self-perpetuating and relatively easy to maintain on poor-to-medium sites. Oak species made up the highest percentage of advance understory on poor sites in two studies *(Arend and Gysel 1952, Weitzman and Trimble 1957)*. Carvell and Tryon *(1961)* showed that high light intensity and southern exposure are positively correlated with oak abundance on poor sites.

On the better sites, intense competition makes it difficult to reproduce oak stands. Arend and Scholz *(1969)* described problems in regenerating red oak on good sites in the Lake States. On good sites in southwestern Wisconsin, a current survey of clearcut areas being made by the North Central Forest Experiment Station shows that present management practices are not providing sufficient red oak reproduction. Curtis *(1959)* postulated that such stands arose after a history of severe fire and that succession is toward more mesic species.

Stand history plays a key role in the amount of advance oak reproduction present. In a West Virginia study, stands that had been thinned, grazed, or lightly burned during the past two decades generally had more oak reproduction than undisturbed stands *(Carvell and Tryon 1961)*. Disturbed stands had more light reaching the forest floor and consequently had more reproduction. Recent research in Missouri showed that all young oak reproduction died in a 70-year-old stand with an overstory density of 100 square feet of basal area per acre, but that a stocking of 80 square feet permitted the reproduction to survive and increase slowly in number.

Reducing competition undoubtedly influences establishment of oak seedlings. Elimination of understory brush with herbicides in an 80-year-old white oak stand in Iowa resulted in a much better reproduction catch from a bumper acorn crop than did no treatment. Untreated plots had only 2,100 oaks per acre, while treated plots had 7,900. Because fire has obviously played an

important role in oak ecology, controlled burning may some day be a useful tool in improving oak regeneration. However, burning, mowing, and herbiciding have not yet been perfected as effective economic tools for oak regeneration.

Dense overstory stocking inhibits oak establishment in several ways. Acorn production is low in dense small-crowned stands. Dense overstories use most of the available moisture, nutrients, and light. During moist years oak seedlings may become established, but they remain small or die during dry or even normal years. Therefore, in the latter part of the rotation, overstory densities should be regulated to encourage the establishment and growth of understory trees.

Where site index is below 70, intermediate cuts to improve the growth and quality of the main stand will also improve reproduction. A series of light partial cuts during the last half or third of the rotation are probably much better than a heavy cut as the stands near maturity. The manager has better control of quality in the overstory, and the position of oak through a gradual buildup is more secure. Heavy cuts favor shrubs and other tree species to the detriment of oaks.

For purposes of reproduction, intermediate cuts should start 20 to 30 years before the harvest cut. Residual stocking should be about 70 percent or roughly 70 to 80 square feet of basal area per acre for small sawtimber-size stands. Some European oak culturists recommend similar stocking levels to encourage oak establishment. For example, in a Bulgarian reference *(Zelev and Dimitrov 1967)* a stocking of 70 to 80 percent was recommended for oak establishment. In Russia, Molcanov *(1962)* suggested 60 to 70 percent stocking for best acorn production.

HARVEST CUTTING

Where advance oak reproduction is lacking and oak is wanted in the new stand, the rotation age must be prolonged. The area to be reproduced, no matter how large or small, must contain reproduction before the final cut is made. Estimates of what constitutes adequate advance oak reproduction have ranged from 400 stems per acre to 4,000. More important than number of stems is size of the reproduction and the number of stump sprouts expected. A thousand oaks per acre 2 feet or more in height should produce a new oak stand unless competition from other advance trees and shrubs is severe. If a large number of pole and small sawtimber-size oak trees are to be cut in the harvest area, there is no need to have a thousand oaks in the advance reproduction. In this case stump sprouts can be expected to augment the reproduction.

As early as 1927 Korstian *(1927)* recommended partial cutting to obtain oak reproduction. For uneven-aged stands with trees of all sizes, he recommended the selection system, in which reproduction would fill openings created by the removal of scattered large trees or groups of trees. He recommended the European shelterwood system for even-aged stands where natural reproduction is obtained through three cuttings. A gradual reduction of the overstory is preferred over a single cutting. However, Korstian agreed with other earlier American writers that in this country the seed cutting is probably unnecessary because of economic limitations and an abundance of advance growth. The pioneer American silviculturists advised the forest manager to take full advantage of advance reproduction. We cannot improve upon that recommendation even with nearly a half century of hindsight. The silvical principles remain the same.

As stated earlier, silvical characteristics call for even-aged silviculture to reproduce oaks. Fortunately, a variety of silvicultural methods can be applied to meet objectives of different owners or managers. For maximum timber production in the shortest time, clearcutting will give the best results. In contrast, long rotations with scattered irregular openings will be the best route for those who want to optimize a combination of values such as timber, wildlife, and esthetics. Both methods and their variants will produce timber, wildlife, and pleasant scenery throughout most of the rotation. Watershed protection values will be essentially the same, provided good logging practices are followed. The silvicultural methods

that can be employed in oak management are summarized below.

Single-Tree Selection

Although single-tree selection is not recommended as a final harvest for oak stands, selection thinning can be used for intermediate or light partial cuttings throughout a large part of the rotation. All oaks except scarlet oaks are long-lived, and the rotation age can be extended for many years by this means. When selection is generally made from below, the long rotation produces high-quality logs. Mast production is very good, and the large trees lend much to esthetic qualities of the stand. However, growth per acre per year is sacrificed during the latter part of the rotation.

Group Selection

Sooner or later all stands must be regenerated. Group selection has less impact on a unit area than clearcutting. Cutting a group of trees provides the necessary room for the new stand to grow into the overstory.

The group or opening size will have little influence on the amount of reproduction. Sander and Clark *(in press)* found no difference in density of reproduction in openings ranging in size from $\frac{1}{20}$ acre to 4 acres. However, reproduction grows slowly on the edges of openings, and the width of the area affected is the same regardless of opening size. Thus small openings have a relatively high proportion of their total area in ineffective edge (fig. 3). For best reproduction growth, circular openings should be at least ½ acre *(Sander and Clark, in press)* and 1 acre is even better. The 1-acre opening is also better for wildlife habitat.

The chief disadvantages of group selection are higher logging and administrative costs compared with the shelterwood or clearcutting methods. The group-selection method is easier to use on small to medium-size ownerships where identification of small areas for management is not an administrative problem.

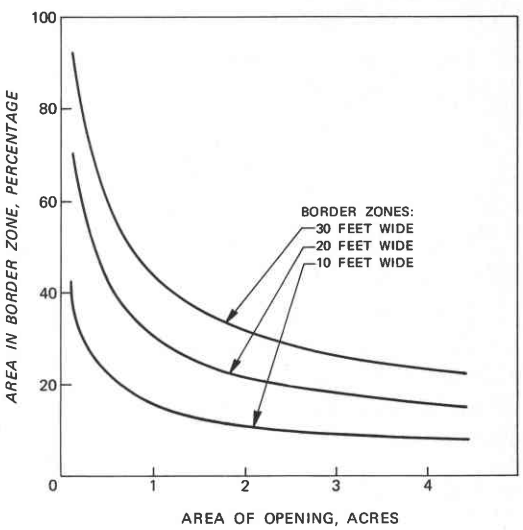
Shelterwood Method

The shelterwood method is recommended by a number of authors, and a good technical review was given by Smith *(1962)*. Conceptually, it is a "safe" system because the final cut is not made until advance reproduction is established. The method has not been applied systematically on an operational basis in the United States, but a number of experimental cuttings have been made. The cuttings have generally failed to increase the amount of oak in the new stand. Perhaps the periods between preparatory cuts were simply not long enough, or the sites were too moist. In some places new seedlings were established but were unable to compete with the faster growing understory of other trees and shrubs.

After a study of advance oak reproduction in West Virginia, Tryon and Carvell *(1958)* suggested the one-cut shelterwood method for harvest cutting where there is abundant advance reproduction. In effect, such a system would be little different from technical clearcutting where there is advance reproduction.

The shelterwood idea is an excellent one for situations where an oak understory is lacking. But we must think of the preparatory cuttings and the seed cutting at least 20 years before the final harvest. The first cut or two must not be so heavy that it will release or establish fast-growing competing species.

Figure 3.—Relation between total area of circular openings and percent of area in border zones 10 to 30 feet wide.



The idealized shelterwood method provides one or more cuts that create optimum conditions for the establishment and development of advance reproduction before the final harvest cut. The first cut is made to encourage seed production and seedling establishment. The next cut or two strengthen the reproduction. The final overstory stand is made up of the best-formed and fastest-growing trees. It should contain about 40 to 50 percent of the original stand basal area. This final shelterwood stand is more open than a stand that has simply received a number of intermediate thinnings.

The advantage of the shelterwood cut is that a vigorous new stand occupies the site before the final harvest. The harvest is stretched over a number of years, and the stand is esthetically more pleasing than a clearcut stand. Mast and browse production should be near optimum for a relatively long period. Some disadvantages are the risk of degrade or windthrow of shelterwood trees, increased logging costs, and destruction of some advance reproduction during logging.

Clearcutting Method

Many oak or mixed stands approaching maturity have enough advance reproduction to be regenerated by clearcutting. When we say clearcutting we mean technical clearcutting, in which the entire overstory stand, merchantable and unmerchantable, is removed at one time. The most important aspect of clearcutting for oak is the absolute requirement that well-developed advance reproduction be present in sufficient quantity to provide a fully stocked stand. This means at least 1,000 well-distributed oaks per acre, 2 to 4 feet in height. If other species can be depended upon to make up a part of a mixed stand, fewer oaks are needed.

Silviculturally, the size of the clearcut is limited only by the continuity of adequate reproduction. Other factors such as owner objectives and esthetics should determine the actual size of the clearcut areas. Some advantages of clearcutting are greater yields per acre, lower harvesting costs, simplified management, and the encouragement of the more valuable intolerant species. Disadvantages often cited, especially when large blocks are clearcut, are unpleasing looks, no mast production from the area for many years, and poor wildlife habitat in the dense sapling and pole stand. These and other disadvantages can be minimized by various management techniques that are entirely compatible silviculturally.

The combination of known and unknown hazards of oak silviculture demands that the forest manager be more than casual in his approach to oak regeneration. Unfortunately, we cannot at this time give exacting prescriptions for foolproof results. Even so, a few simple extensive treatments will greatly enhance the probability of establishing adequate advance reproduction. Most important, areas of deficient reproduction must be positively identified 20 to 30 years before the harvest cut. Remember, a harvest cut is made once in a rotation, and the timing of the cut is the most important single decision the forest manager makes. And the decision cannot be made upon timber values alone. Fortunately, in the oaks we are dealing with long-lived species, and harvests can be delayed for long periods.

Finally, classical cutting prescriptions are no panacea for oak silviculture. We rarely deal with a truly typical or classical situation. Stand conditions vary, and so must oak management. If the manager understands oak silvics, the silviculture will follow.

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FACTORS AFFECTING ACORN PRODUCTION AND GERMINATION AND EARLY GROWTH OF SEEDLINGS AND SEEDLING SPROUTS

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ABSTRACT. Acorn production is extremely variable and unpredictable. Flowering is copious, but many climatic factors influence acorn development from initiation of flowers to acorn maturity. Acorns are consumed by birds, animals, insects, and microorganisms. The establishment of seedlings is more closely related to favorable site factors than to size of crops. A majority of oaks originate from advance reproduction that accumulates under the previous stands during several decades.

FOR THOUSANDS of years our major species of oaks have become successfully established from acorns. With this reproductive mechanism, the oaks have moved back and forth with the glacial periods of the North American continent. They have survived many climatic and geologic changes and many wildfire conflagrations, including the fires of Indians and the fires of pioneers. The oaks have also occupied new sites in competition with many other forest species. On many of the blight-killed chestnut sites in the eastern United States, the upland oaks have replaced dead chestnut trees *(Korstian and Stickel 1927; Woods and Shanks 1959).*

Our purpose in this paper is to discuss the factors that affect the production and germination of acorns, and the early growth of seedlings and seedling sprouts.

There are hundreds of published observations and scientific studies on these subjects. We have exercised our judgment to condense existing knowledge into general concepts. These concepts are presented to provide a framework of knowledge to guide practical decisions, as well as to identify some research needs. We have cited key papers that will lead the inquiring person into the details of anatomy, physiology, and growth and development of flowers, acorns, and seedlings. Much of this literature pertains either to the genus as a whole, or to additional species of oak other than the five upland species that are the subject of this symposium. Even within this group

of five upland species, there are wide differences in the processes of sexual reproduction and early growth, and we must use caution in applying generalities to guide both practice and research.

FLOWER FORMATION

Acorns, the fruit of the oaks, develop from fertilized flowers, never from unfertilized flowers by such asexual methods as parthenogenesis and apomixis. All species of oak produce both male and female flowers on the same tree. Both staminate (male) and pistillate (female) flowers are formed every year in great abundance by practically every oak tree of flowering size and age; consequently, the year-to-year variability in size of acorn crops is not due to lack of flowering capability, nor to cyclic formation of flowers.

The pistillate flowers are located in the axils of the new leaves, whereas the staminate flowers develop on long slender catkins that are borne either in the axils of scale leaves of the current vegetative buds or in separate male buds *(Stairs 1964)*. Pollination is by wind and air currents.

Climatic factors are most important in controlling flower formation and development, and in the pollination of flowers. There are no important biotic factors that affect the formation of oak flowers. Various climatic factors, such as wind, late frost, prolonged rain, relative humidity, and temperature have been shown to affect the opening and closing of the anthers and the dissemination of pollen *(Sharp and Chisman 1961)*. A study of pistillate flowering and acorn development in Pennsylvania showed that good crops of white oak acorns were obtained when a warm 10-day period in late April was followed by a cool period in May *(Sharp and Sprague 1967)*. At present, there are no known ways to control flower formation and development or the pollination of flowers.

The ability to control these processes would be a valuable tool for the forest manager. Abundant flowering and high rates of pollination would insure more consistent acorn crops for reproduction and wildlife food. On the other hand, low flower production would leave larger food reserves for the growth of wood and other vegetative organs.

FRUIT FORMATION

Early ovule development begins approximately 1 month after pollination in the subgenus *Lepidobalanus* (white oaks), and approximately 13 months after pollination in the subgenus *Erythrobalanus* (red oaks). Although there is a major timing difference between the two groups before fertilization, the subsequent developmental stages of the embryo are relatively uniform from a cytological or morphological viewpoint. Therefore the major difference of interest is the time required for seed maturation. The white oak group matures seed in one growing season; the red oak group requires two growing seasons *(Stairs 1964)*.

The greatest loss in fruits occurs because of premature abscission. The highest rate of loss occurs during the period of pollination and fertilization *(Turkel, Rebuck, and Grove 1955)*, although abscission of immature acorns continues until maturity. We do not know the reasons for these abscissions, but we do know that trees with large crowns have about the same pattern of abscission as trees with small crowns *(Williamson 1966)*. Open-grown trees do not produce any more flowers and acorns than do trees with the same crown surface area in closed stands. However, the surface area of oak crowns in closed stands can be increased by thinning, because crown surface area for trees of a given age depends to a large degree on stand density. Limited evidence in Russia also suggests that increasing the growth rate of shoots by cultural practices such as thinning may increase fruit-bearing in the oaks *(Polozoya 1958)*.

The number of acorns produced by a tree also may be an inherent characteristic *(Irgens-Moller 1955; Sharp and Sprague 1967)*.

SIZE AND PERIODICITY OF CROPS

Numerous investigators have estimated the size of acorn crops from one to several years, and in all parts of the world where

oak forests occur. Both timber and wildlife managers are intensely interested in the seed production of oaks, the timber manager because of the reproductive needs of the forest, and the wildlife manager for the store of food used by important game birds and animals.

It has been commonly observed by all of these investigators that acorn crops are extremely variable from tree to tree, from species to species, from location to location, and from year to year *(Beck and Olson 1968; Christisen 1955; Christisen and Korschgen 1955; Downs and McQuilken 1944; Gysel 1956; Minckler and Janes 1965; Tryon and Carvell 1962a, 1962b)*. The factors causing this variability are not known, though many attempts have been made to discover them *(Gysel 1958; Williamson 1966)*.

On a land-area basis, acorn crops vary from nearly zero to 250,000 or more acorns per acre. Many times the white oak group will produce heavily in a particular year, and the red oak group will have practically no yield, and vice versa *(Barrett 1931; Gysel 1956; Beck and Olson 1968)*. In mountainous terrain, the wide variability in microclimate due to elevation and aspect results in comparable variability in acorn production. There is need to develop an index of production that can be used to predict mast for animal food from both the white and red oak groups *(Gysel 1958)*. Since we do not have practical means for controlling the size of acorn crops, wildlife managers advocate the culture of mixed oak stands over a range of sites to minimize the likelihood of complete crop failure *(Christisen 1955; Collins 1961)*.

DESTRUCTION OF ACORNS

Acorns are consumed by birds, animals, insects, and microorganisms *(Korstian 1927)*. Two groups of insects, nut weevils and gall insects, cause the largest losses of acorns *(Barrett 1931; Beck and Olson 1968; Downs and McQuilken 1944)*. Brezner *(1960)* found that in Missouri the weevils of the genus *Curculio* were the principal agents of acorn depredation. Dorsey *(1967)* showed that the systemic insecticides Bidrin and phorate were effective in reducing acorn losses by the acorn weevil *(Curculio* spp.*)* when the insecticides were injected into the boles of the trees.

The percent of sound acorns capable of germination is closely related to size of crop *(Beck and Olson 1968; Korstian 1927; Minckler and Janes 1965)*. In poor years, nearly all acorns are consumed. The number of new seedlings added to the advanced regeneration each year is also directly related to size of the acorn crop.

In addition to consumption by organisms, acorns are destroyed by other means, such as freezing, drying out, burning in wildfires, and flooding. These destructive forces account for relatively large losses in poor crop years and relatively small losses in good crop years.

GERMINATION OF ACORNS

Sound, undamaged acorns have a germinative capacity between 75 and 95 percent *(USDA Forest Service 1948)*. Acorns of the white oak group germinate in the fall immediately after falling to the ground. Acorns of the red oak group overwinter on the ground and germinate the following spring. For germination to occur, the moisture content of acorns must not drop below 30 to 50 percent for white oaks, and 20 to 30 percent for red oaks *(Korstian 1927)*. Litter or soil cover affords protection against drying and is necessary for successful germination *(Barrett 1931; Korstian 1927)*. Germination is hypogeal, and under favorable conditions is generally complete in 3 to 5 weeks *(USDA Forest Service 1948)*.

In a West Virginia study, Carvell and Tryon *(1961)* found that, from equal numbers of red and white oak acorns, the number of white oak seedlings produced was five times as great as the number of red oaks. This situation appears to be the usual one, but the reason for the difference is not known. White oak acorns generally fall earlier than red oak acorns and are smaller than red oak acorns. Since the smaller white oak acorns germinate immediately and are covered by deeper leaf litter than are the red oaks, white oaks are

probably afforded greater protection from damaging agents.

The establishment of oak seedlings in West Virginia was found to be more closely related to favorable site factors than to size of acorn crops *(Tryon and Carvell 1958, 1962a, 1962b)*. However, this relationship varies widely for the different species of oaks and regions of the country.

EARLY GROWTH OF SEEDLINGS AND SEEDLING SPROUTS

The principal factors that influence the development of oak seedlings are light intensity and soil moisture *(Bourdeau 1954; Kozlowski 1949)*. The five upland oak species under discussion in this symposium are intermediate in shade tolerance and reach maximum rates of photosynthesis at lower light intensities than intolerant species such as the southern pines *(Kramer and Decker 1944)*. As a result, these oaks can compete favorably in a broad range of light climates if soil moisture is adequate. The exclusion from poor sites of the oak species normally found on good sites (northern red, scarlet, and white oaks) is because of insufficient drought resistance of the better oaks. The exclusion from good sites of poor-site oaks such as blackjack oak is explained by the low shade tolerance and slow rate of growth of blackjack oak.

Merz and Boyce *(1958)* found that 88 percent of the oak reproduction became established prior to both light and heavy harvest cuts. The amount and distribution of oak reproduction found in the harvest cuts is not necessarily related to the cutting intensities. A majority of oaks in the new stands grow from seedling sprouts that have accumulated over several decades prior to the harvest cut. The major oak species in these areas was white oak. Some of the red oaks, mostly northern red and scarlet oak, do not persist as advanced reproduction for more than a few years.

McGee *(1967)* found abundant oak regeneration under eight mixed oak stands in the Southern Appalachians prior to installing a study of cutting intensity. He observed a dynamic fluctuation in the advance regeneration as seed germinated, seedlings lived a few years, died, and were replaced by new ones.

There is a high mortality of newly established oak seedlings on all sites. Death is highest in the first 6 years of the seedling's life. Few seedlings survive the first year without dying back and sprouting at least once. Some seedlings (mostly white oak) survive under dense canopies for periods up to 50 or more years by a repeated process of sprouting and dying *(Merz and Boyce 1956; Merz and Boyce 1958; Minckler and Janes 1965)*. This survival is made possible by the large number of buds that occur on new seedlings and subsequently develop near the ground line of the long-surviving individuals. Near the base of new shoots a large number of buds is formed in the axils of rudimentary leaves. These leaves look like tiny hairs. The buds in the leaf axils, which may remain in suppression for many years, and the three buds in the axils of each cotyledon *(Kurmes and Boyce 1964)*, form a reservoir of buds for repeated sprouting of shoots.

When the top of a young seedling dies back, one or more of the suppressed buds grow. These buds are often below the soil surface, and are protected from damage. Such characteristics make it possible for oak seedlings to survive after the tops are destroyed by animals, insects, disease, logging, and fire. In this manner, seedling sprouts of oaks accumulate beneath the canopies of existing stands *(Liming and Johnston 1944)*.

Various forms of partial cuts prior to final cuts have been recommended to regenerate the oaks from current seed crops, but there are no certain ways to manage stands of oak for the abundant production of acorns. Methods of management have been developed to favor the accumulation of advanced oak regeneration. These methods are discussed in other symposium papers.

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SEEDING AND PLANTING UPLAND OAKS

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ABSTRACT. Upland oaks can be established by seeding or planting, but additional experience is needed before these methods become economical alternatives to natural regeneration. Recently forested sites are generally more favorable than abandoned fields. Lack of repellents to protect acorns from animals severely limits direct seeding, but oaks can be planted readily by conventional methods and will survive well on suitable sites. They require ample sunlight for best growth, and competing vegetation must be controlled. At best, however, early height growth is discouragingly slow. Advances in cultural methods and the development of genetically improved stock seem essential to make artificial regeneration practical.

ARTIFICIAL regeneration of upland oaks has never been widely practiced in the United States. A major reason is that natural regeneration is usually so abundant on cutover areas that there is little need for planting or seeding. In addition, oak planting and seeding have been fraught with difficulties. For a similar effort, and with less risk, faster-growing and more valuable hardwoods can be established—yellow-poplar and black walnut, for example.

Although artificial regeneration may never be a primary means of establishing oak forests, it will be needed where cutover areas are poorly stocked, where natural regeneration fails, or when genetically superior stock is to be established. We have much to learn, however, before planting or direct seeding can be practical alternatives to natural regeneration.

Recently cutover forests generally offer the best prospects for oak seeding or planting. As we gain a better understanding of site requirements, abandoned fields suitable for oaks may be selected with more confidence.

CONTROL OF COMPETING VEGETATION

Planted or seeded oaks can survive for many years even where competition is intense enough to reduce growth drastically. For satisfactory development, however, the seedlings require ample light. Northern red oaks grow better in full sunlight than in partial shade, even during their first year from seed *(McGee 1968)*. On Tennessee's Cumberland Plateau, planted white oak and black oak seedlings have growth somewhat faster where all hardwoods were controlled

than under an overstory of 30 square feet of basal area per acre *(Russell and Rollins 1969)*. The ideal preplanting treatment for cutover lands is one that completely removes unwanted hardwoods and brush.

We lack precise information concerning the response of most species to cultural treatments, but it appears that mechanical site treatments, herbicides, or fire—alone and in various combinations—can be used effectively. Choice of method will depend on whether the site is forest or open land, and on the composition and density of existing vegetation. The essential point is that the methods of controlling competion are no different in principle than for other species.

On forested sites, dense understory vegetation is more detrimental than is a high overstory. Grasses and weeds are not initially a problem, although they invade good sites rapidly after existing hardwoods are deadened. As a minimum, unwanted species must be controlled until desirable oaks are established well enough to stay ahead of competition.

Herbicides are often considered to be the most practical way to prepare sites on steep slopes or rocky soil, or where planting areas are too small for efficient operation of heavy equipment. Mist-blowing with herbicides, after injection of overstory trees, is common procedure for initial control of understory hardwoods and shrubs. These treatments seldom give complete kill, and on better sites the slow-starting oaks may be suppressed within 3 or 4 years.

Mechanical clearing of woody vegetation may give more complete and longer-lasting control than chemical methods do. Disking or chopping should be potentially less damaging than methods such as blading, which may strip off considerable topsoil.

Follow-up weeding will be needed on most chemically prepared sites, and on some that have been mechanically prepared. In natural stands total release of sapling oaks has reduced height growth *(Allen and Marquis 1970)*. Thus, weeding should probably be limited to freeing only overtopped or severely crowded trees, and complete removal of all unwanted hardwoods should not be attempted.

Dense stands of broadleaf weeds or heavy sods on old fields must be eliminated. Here herbicides may be cheaper and more effective *(Erdmann 1967)* than treatments such as furrowing, plowing, and disking. After oaks have been planted, competition can be controlled by cultivating, mowing, or applying herbicides. Mulching controls weeds; but rabbits, attracted by the open area around seedlings, have severely damaged planted northern red oak *(Pruett 1959)*. Presumably, spot herbicide treatment or hoeing might create a similar hazard.

DIRECT SEEDING

Provided competition is controlled, the upland oaks can be established by planting either seedlings or acorns. Direct seeding is cheaper than planting, and the seedlings start life with normal root systems. Possibly more research has been done with direct seeding than with planting, but with less success. Considerable is known about seed handling, sowing methods, and season of sowing. The greatest obstacle is the lack of economical ways to protect acorns from animals.

Acorns are damaged by freezing, and their viability drops rapidly if they dry out *(Korstian 1927)*. Few surface-sown acorns produce seedlings, even where they are protected with screens *(Sluder 1965, Sluder et al. 1961)*. Sowing at depths of 1 to 2 inches usually is satisfactory.

Deep hardwood litter does not reduce germination, but may retard seedling emergence or lessen survival. In Iowa, establishment of four species of oaks was best where acorns were planted and litter was removed *(Krajicek 1960)*. Poorer catches on litter-covered seed spots resulted from losses to disease and insects, as well as somewhat heavier rodent depredations, rather than from any mechanical barrier to seedlings. On a cutover site in Tennessee, however, disking before sowing had no effect on white oak establishment *(Mignery 1962)*. Where hardwood litter is a problem, it can be eliminated easily by burning. Presowing mechanical treatments to control woody

competition will also reduce hardwood litter as a secondary benefit.

Neither burning, disking, plowing, nor furrowing had any important effects on northern red oak seeding on an old field in Ohio *(Plass 1952)*. If dense sods or weeds are treated in advance to control competion, additional seedbed preparation is probably not justified on such sites.

Acorns store best at low temperatures, under conditions that minimize moisture loss and provide oxygen for respiration. Since these conditions are equivalent to stratification, storage effectively overcomes dormancy in the red oaks. Cold storage at slightly above 32°F. retards sprouting and weevil activity better than storage in an outdoor soil pit. Acorns of the white oak group are nondormant but can be held safely over winter in cold storage.

The upland oaks can be seeded in fall or spring. Spring sowing is sometimes recommended to shorten the period of exposure to seed-eating animals—chiefly squirrels, chipmunks, and mice—but repeated trials have failed to show any consistent differences in animal pressures between seasons *(Nichols 1954, Sluder 1964, 1965)*. While predator populations may be higher in fall than in spring, alternate foods usually are more plentiful also.

On the Cumberland Plateau we have obtained good results by seeding white, black, and northern red oaks at various dates from October through May. Recently, unstratified northern red oak acorns, planted under screens in December, yielded a seed-spot stocking of 93 percent. For stratified seed of the same lot sown in April and July, seed-spot stocking averaged 70 and 93 percent. Season of sowing is apparently not critical where animal depredations are controlled.

Planting acorns as deeply as possible, consistent with good germination, helps reduce losses to small mammals. Though removal of hardwood litter over large areas has been recommended *(Nichols 1954)*, heavy damage to northern red oak acorns occurred on barren strip-mine spoil in central Pennsylvania *(Bramble and Sharp 1949)*. Plowing and disking to remove vegetative cover also failed to limit losses of northern red oak acorns on an old field in Indiana *(Crozier and Merritt 1964)*. Depredations by both mice and squirrels occurred at distances up to 93 feet from an adjacent hardwood forest. Even if animal pressures are lower towards the centers of large clearings, a considerable acreage around the edges may be lost.

Screens afford a high degree of protection but are too costly to be practical. Until repellents become available, planting remains the surer method of artificially regenerating oaks.

PLANTING

Conventional planting techniques have proved successful in several regions. On cleared forested sites in central Tennessee, first-year survival of white, black, and northern red oaks is usually better than 90 percent. In the southern Appalachians survival after 2 years averaged 94 percent for six northern red oak plantings spanning a range of site indexes from 76 to 98 feet at age 50 years *(Olson and Hooper 1968)*. Planted northern red oak has survived well also in the Lake States *(Arend and Scholz 1969, and Scholz 1964)*.

Establishing a stand should not be difficult on suitable sites. Excessive mortality most often results from planting stock that is of poor quality or has been carelessly handled and stored.

Though survival is usually good, rapid early growth of oaks cannot be expected. Even on the best sites, growth for 2 or 3 years after planting is seldom more than a few inches a year. Growth accelerates after seedlings become established and if they are kept free from overtopping woody competition or dense weeds. Northern red oak in central Tennessee, for example, generally averages about 1 foot per year from 5 through 10 years after planting.

Upland oaks are fairly hardy, and bare-rooted stock performs well under a wide range of conditions. Most planting is done with 1-0 seedlings; 2-0 stock is occasionally used. Size is a better measure of quality than age alone. Seedlings with stem diameters of $\frac{7}{32}$ inch at the groundline are pre-

ferred for planting of northern red and chestnut oaks in the Central States *(Limstrom 1963)*. The minimum size recommend is 5/32 inch.

Few studies have been made of the effect of morphological grade on field performance. In North Carolina, northern red oaks from 5/32 to 9/32 inch in rootcollar diameter grew better for 2 years after planting than those larger than 9/32 inch *(Olson and Hooper 1968)*, though they did not fully make up initial differences in height. In the Tennessee Valley, large northern red oak seedlings have grown considerably faster than bed-run seedlings *(Foster and Farmer 1970)*.

If they are to reach the desired size in 1 year, seedlings must be grown at a low density in the nursery. In a Tennessee nursery, 1-year-old northern red oak grown at a density of 12 per square foot averaged only 0.17 inch in diameter at the groundline and 9.4 inches in height *(Taft 1966)*. At a density of 4 per square foot, seedlings were 0.26 inch in diameter and 15.7 inches tall.

Roots and tops are often pruned to make packing and shipping cheaper. Preferably, seedlings should be root-pruned in the nursery before they become dormant. Top clipping is done when they are dormant. Seedlings can be field-pruned for ease in handling and planting if they were not pruned at the nursery. Cutting roots shorter than about 8 inches is unnecessary and may adversely affect initial survival or growth.

Seedlings should not be allowed to dry out, heat, or freeze during shipment or in storage. They can be kept safely in bales for about a week in a cool shaded place. They can be heeled in for longer periods, but should be planted before new leaves unfold. Refrigeration at about 36°F. is best for long-term storage *(Limstrom 1963)*. At Sewanee, cold storage has kept seedlings in good condition and dormant for at least 5 months.

Optimum planting dates will vary with the local climate. Seedlings planted in the fall or winter may be injured by frost-heaving, particularly on heavy soils or where all vegetation has been removed; hence spring planting is usually preferable. Where summer temperatures are moderate and rainfall is dependable, dormant seedlings can be planted well into the growing season *(Russell and Rollins 1969)*. On Tennessee's Cumberland Plateau, white and black oaks planted in August and September were shorter after 4 years than those planted at monthly intervals from April through July, but survival was good in all but the September plantings.

Whether machine or hand methods are chosen will depend primarily on the size of the planting area, its soils and topography, and the density of trees, brush, or logging debris. For ordinary nursery stock, and on most soils, bar-slit planting or machine planting is as good as the more expensive hole planting. Hole planting is necessary only for rocky sites or for very large seedlings. Regardless of planting method, seedlings should be set with the rootcollar slightly deeper than in the nursery.

The possible gains from planting container-grown hardwoods have aroused much interest. In one test, northern red oak grew better in paper tubes filled with peat potting mixture, and other containers that provided good aeration, than in paper tubes filled with soil *(White et al. 1970)*. Such methods may become more widely used when the techniques are perfected, particularly if they can markedly increase growth.

PLANTATION INJURIES

Insects seldom cause serious losses in young plantations. Animals are a greater problem. Severe and repeated browsing by deer and rabbits may reduce survival and growth considerably. Oaks are less palatable than many other woody plants, however, and are also vigorous sprouters, so that top-clipped seedlings soon recover from moderate damage. Mice and voles girdle seedlings near the groundline and have caused heavy mortality, particularly on old fields.

Deer and rabbit populations can at times be controlled by managed hunting. Repellents can be used *(Besser and Welch 1959, Hildreth and Brown 1955)*, but repeated applications may be needed since contact repellents do not protect new growth. Mice and voles can be controlled by poisoning.

Such direct measures are expensive, however, and are not justified unless severe losses are likely.

More extensive planting experience may reveal unanticipated problems. But oaks are no more susceptible to animal attack than most hardwoods, and the threat of damage to seedlings should not discourage planting where conditions are otherwise favorable.

OUTLOOK

The prevalent belief that oaks are difficult to plant or seed is not entirely justified. They can be established readily with ordinary nursery stock and standard planting techniques. They could easily be direct-seeded if dependable repellents were available.

The major limitation to planting is the slow initial growth. Some possibilities for speeding growth include improved planting stock, better methods of competition control, and fertilizers. That early growth can be increased substantially is indicated by a recent study in Tennessee. Here the use of selected stock and nitrogen fertilizer produced northern red oak saplings averaging over 6 feet in height 4 years after planting *(Foster and Farmer 1970)*. For the long term, genetic improvement may be the most promising way of getting oaks to grow at acceptable rates.

Improvements in any of these areas will help. For maximum gains we must learn how to apply effective cultural measures to high-quality seedlings that have the genetic capability for superior performance. Until this is done, artificial regeneration of the oaks will remain largely in the experimental stage.

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TREE IMPROVEMENT RESEARCH IN OAK SPECIES

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ABSTRACT. Early efforts at developing new forms of oak by interspecific hybridization have not been very successful, although spontaneous hybrids appear rather readily in nature. Preliminary reports on a few seed-source or provenance studies indicate that differences among sources are generally less than differences among trees within sources. This directs tree-improvement programs along the line of single tree selection. Selection methods followed in several programs are briefly outlined, and it is suggested that breeding programs to develop oak wilt resistant individuals be started immediately.

THE OAKS consist of a "typical genus of angiospermous trees of the North Temperate Region" *(Stebbins 1950)*. The genus includes 250 to 300 species, but many of these are probably subspecies of a smaller number of polytypic species. All the oaks studied cytologically have a chromosome number of $2n = 24$ (the diploid state).

Although all the oaks have the same chromosome number, it is well recognized that there is a great deal of variation within the species. The oaks apparently hybridize quite readily in the field *(Stebbins 1950)*, although artificial hybridization in this country has, up to now, been very unrewarding *(Schreiner 1962, Taft 1966)*. Because of the great amount of inherent variability available, tree-improvement programs with oak species should progress at a rather rapid rate, using the standard selection techniques. There are few biosystematic studies to verify this fact, but any forester who has spent time looking at individual trees will acknowledge the fact that among oak trees one can find great variation in form, leaf shape, and growth rate.

At West Virginia University we have begun a biosystematic study of red oak. After measuring one plot of 50 trees in an even-aged stand, we noted that diameter breast height varied from 7.1 to 15.0 inches; total height, 49 to 77 feet; clear bole, 7 to 34 feet; height to first live branch, 8 to 34 feet; height to first fork, 12 feet, to trees that retained terminal dominance completely; number of epicormic branches, 0 to 25; bole straightness, excellent to poor; bark thickness, 0.28 to 0.45 inch; and crown radius (average of four measurements at cardinal directions), 5 to 14.5 feet. Specific gravity varied from 0.549 to 0.656. With this magnitude of variation, and as-

suming even medium heritabilities, a selection program should be very rewarding.

Active red oak selection programs are being carried out in Illinois *(Boyce 1963)*, Indiana *(Rambo 1966)*, Tennessee, Kentucky, North Carolina *(Taft 1966)*, Ohio *(Kriebel and Thielges 1969)*, and West Virginia. A few white oak selections have been made in West Virginia, and both white and chestnut oak selections have been made in the TVA program *(Taft 1966)*. Although the selection procedures vary, the goals of these programs are similar: to develop seed orchards that will produce trees with rapid diameter growth, straight boles with no spiral, good natural pruning, and few or no defects.

Emphasis in most selection programs is on the butt log, which gives the highest monetary return. Actually, even though the butt log grades No. 1, the second log will normally grade No. 2, and the third No. 3. According to Taft *(1966)* the No. 3 log will not produce enough income to pay for its processing.

SELECTION METHODS

Four selection techniques are in use:

Method 1

This method is generally used in the conifer selection program. The select tree is graded in comparison to several (usually five) crop trees growing as nearly as possible on the same site as the candidate tree. However, oaks normally grow in mixed stands, and often there are too few trees sufficiently close to the candidate tree for efficient comparison.

In the West Virginia program, we use any number of available comparison trees up to the desired five. The justification for this is simply that two trees give a better estimate of the site potential than does one.

In all the selection schemes, there are certain characteristics that disqualify a candidate tree. Primary among these is bole quality, which includes spiral grain (as evidenced by bark spiral or actual spiral of the bole) and lack of straightness. The candidate tree must be free of epicormic branches. A minimum number of "other defects" as defined in "A Guide to Hardwood Log Grading" *(Ostrander 1965)* may be tolerated.

Characteristics such as height, volume, branch diameter, and crown characteristics are graded on a comparative basis, using the best neighboring comparison trees as a base. Where an outstanding selection has no comparison trees, it is graded on its own merits; and the fact that there were no suitable comparison trees is noted on the grading form.

Method 2

The TVA system as used by Taft *(1966)* includes no comparison trees. Each candidate tree is graded on its own merit. Eight factors are considered. If the first two (straight grain and perfect bole straightness for two logs) are not satisfactory, the tree is discarded. The next two (defect and uniform, relatively fast growth rate) restrict selection to well-formed vigorous trees. The last four (high form class, desirable wood properties, total height, and crown characteristics) are given minor consideration.

Method 3

The selection for white oak seed parents in the tree-improvement program of the Central States Forest Experiment Station is based solely on log quality as evidenced by number of lateral branches and suppressed lateral buds. By pruning the select trees to a height of 17 feet and making a phloem block, suppressed bud development is encouraged. If, at the end of the next growing season, the number of new branches plus the number of old branches is 8 or fewer, the tree is included. Progeny testing follows to verify the selection *(Boyce 1963)*.

Method 4

By comparison, Kriebel and Thielges *(1970)* have selected a number of superior red oak stands in Ohio on the basis of phenotypic appearance, emphasizing growth rate and form. Original selection included 60 stands. The 20 best stands were then defined, and 10 superior trees were selected in each stand. Open-pollinated seed was collected from 3 of the best trees in each of the 20 stands for progeny testing.

If the better progenies come from certain stands, these stands will be developed for immediate seed production. If the better progenies are randomly distributed, the progeny test areas themselves may be converted to seedling seed orchards. If outstanding individuals are defined in the progenies, and if it is determined that vegetatively propagated orchards will produce seed at an earlier age, grafted seed orchards will be established. Before the seed orchards are bearing seed in commercial quantities, the seed production areas should provide genetically improved seed for interim planting *(Kriebel and Thielges 1969)*. Presumably this seed will be intermediate in genetic quality between field-run seed and that to be collected from the seed orchards.

Each of these methods has minor advantages and disadvantages. However, without progeny testing, any system is merely an exercise, as the validity of the selection method is proved by the performance of the progeny. Progeny tests, therefore, are an integral part of each method. Until the progeny test results are available, one can only speculate about which method will provide the greatest improvement.

PROVENANCE

Though the oaks have a considerable range, there are few provenance studies in this genus. Shreiner *(1970)* indicates that such testing is being carried on with white oak, cherry bark oak, northern red oak, and scarlet oak. To this list should be added the provenance test of southern red oak initiated at Clemson University under the S-23 cooperative program (Schoenike; personal communication, 1969), and chestnut oak in the TVA program *(Taft 1966)*. Although the Michaeux Quercetum at the Morris Arboretum has no formal seed-source studies, various species are represented by seed from several geographic locations.

Santamour and Schreiner *(1961)* reported on geographic variation in five white oak species in the Michaeux Quercetum. Data recorded were time of germination, 1- and 3-year height growth, and autumn coloration. For white oak, chestnut oak, post oak, bur oak and overcup oak, they concluded that individual tree selection would be more promising as an improvement technique than racial or ecotypic selection.

Schreiner and Santamour *(1961)* also studied the same four characteristics in seedlings of blackjack oak, northern red oak, black oak, scarlet oak, and southern red oak, and concluded that—with the possible exception of blackjack oak—individual tree variation was of greater importance than geographic seed source in the red oak group also.

Taft *(1966)* noted in the TVA study that although acorn size varied greatly, there was no correlation between acorn size and seedling size.

From an elevation study of northern red oak, including samples from 2,700, 3,300, and 5,000 feet, McGee *(1970)* found differences in both growth and frost damage. The test plantation was established at an elevation of 2,100 feet. The first-year growth advantage of the lower-elevation seedlings was not considered significant because the seeds were larger than those from the highest elevation. Bud break was earlier for the two lower elevation sources in both the second and third growing seasons, but frost damage, primarily to these two sources, nullified growth gain; and at the end of the third growing season there was no difference in height among sources. It may be that, where elevation is important, some sort of zoning will be necessary.

In 1960, the North Central Cooperative Regional Committee (NC-51), initiated a cooperative northern red oak provenance test, headed by Howard Kriebel of the Ohio Agricultural Experiment Station. Cooperating states are Ohio, Indiana, Illinois, Kansas, Nebraska, Iowa, Minnesota, Wisconsin, and Michigan. The studies include 29 sources on a region-wide basis, and two additional sources are represented in a few tests *(Kriebel 1965)*.

Early information on seed characteristics and seedling growth showed considerable variation among sources. The most northern sources had lighter, smaller, narrow acorns with deep cupules, while the southern sources had broader, heavier acorns

with shallow cupules. In the 1961 planting, which included sources from throughout the natural range, there was a great deal of variation in seed size, most of the variance being due to seed source. However, in the 1963 planting, which included fewer sources and excluded the more northern sources, about one-fourth of the variance for seed size was due to source, while the other three-fourths was due to differences among mother trees. As in the TVA study, seed size was not correlated with seedling size except for two instances, which the author suggested could have been a chance relationship. Measurement of growth rate indicated a strong relationship with geographic origin when the planting with wider geographic coverage was considered. But when the second planting with restricted geographic range was analyzed, again there was a stronger within-source or mother-tree effect *(Kriebel 1965)*.

Presumably, at the termination of this study, each State included in the plantation distribution will have a strong indication of the best source of seed for their red oak planting stock. If the classical breeding procedure as outlined by Wright *(1962)* is followed, the next step would be to make superior tree selections in the indicated area for seed-orchard development. If seed from one area should perform best in most or all States, one or two seed orchards could be established to provide seed for nearly everyone. If different sources or the local source should prove best, individual seed orchards will have to be developed for each State.

In the event that the tree-to-tree differences in the seed-source study are greater than those among sources, single tree selection over the entire range might be most productive. The best phenotypes could then be used in a single large orchard without regard to the portion of the range from which they originate, and seed from such an orchard could be used range-wide.

Without the information derived from such a provenance or seed-source study, individual tree selections from a number of restricted locations will have to be used; and the seed from orchards so designed would be returned to the area covered by the selections.

HYBRIDIZATION

The selection phase of oak breeding has been implemented only very recently. Original genetic work in the genus *Quercus* centered on interspecific hybridization to produce better forms by combining species. Much of the early work was centered in Europe where, for example, some 200,000 hybridizations were made in 47 different interspecific combinations at the Ukranian Research Institute *(Piatnitsky 1960)*. Piatnitsky noted that 50 to 60 percent of the flowers pollinated set and produced acorns. He did not specify the number of seedlings that resulted from this seed, but stated that second-generation hybrids were being grown.

Breeding arboreta in the United States include the Michaeux Quercetum at the Morris Arboretum, the Arboretum at the Ohio Agriculture Experiment Station, Clemson University, and TVA *(Taft 1966)*. Schreiner *(1962)* summarized the crosses made by personnel of the Northeastern Forest Experiment Station from 1937 to 1941. Ten species were used as female parents and these were crossed with 8 species as the male parent. From 6,936 flower clusters pollinated, 242 germinable acorns resulted. Approximately 170 control-pollinated seedlings were actually outplanted, and 153 of these were from the white oak intraspecific cross. Results from 1947-48 breeding programs were no more encouraging.

Apparently both intra- and interspecific hybridization are difficult in the oaks. Schreiner attributes some of the difficulty to the lack of dependable hybridization techniques; but even with the best technique, production of hybrid seed in commercial quantities will probably be extremely difficult.

Vegetative propagation of mature oak is also difficult. Grafting can be accomplished with varying degrees of success. Cuttings cannot be rooted. All these difficulties make it abundantly clear that oak improvement

will necessarily be accomplished through selection with some type of seed-orchard program.

Breeding for resistance to oak wilt is a feasible procedure, but techniques for seedling inoculation and methods of recognizing resistant specimens will be difficult to develop. The financing of such an ambitious project will also be difficult.

The author is informed that the one red oak that might have had inherent resistance has died, apparently from oversampling. The stump should be watched for possible sprouting. Scion wood was collected from this specimen for grafting, but none of the grafts was successful. Perhaps scions from sprouts would graft more readily. This tree would be a good starting point for genetic resistance.

Because we do not have an effective means of oak wilt control, and the upland oaks make up such a considerable portion of the Appalachian hardwoods, a comprehensive genetic program for developing genetically resistant stock should be started without delay. Without control of oak wilt, the oak breeding programs now in progress will be less effective. In the long run, well-formed fast-growing oak trees will be of no use if they cannot survive this disease.

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SILVICULTURAL ASPECTS OF INTERMEDIATE CUTTINGS

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ABSTRACT. Correct timing of the first thinning in mixed oak stands depends largely on the composition and condition of the stands and on available markets for small wood products. Delaying first thinnings in high-quality seedling-origin stands until a long, straight, clear bole has developed is of primary importance in assuring high quality of the final crop trees. However, many of our present stands, particularly those of sprout origin, need improvement work; and improvement cuttings or thinnings should be started as soon as a commercial operation is possible. Growth response in diameter after thinning is usually a gradual process. Older oaks seldom show spectacular changes in diameter growth rate after release.

THINNING

TO THIN OR NOT to thin? This is the question. There appear to be two conflicting views about the place for thinnings in the management of even-aged, pole-stage oak stands. One view, expounded by European foresters, is that oak stands should be kept tightly closed, except for early light cleanings, until after full height growth is attained. This would place the first commercial cutting in the young-timber stage, thus precluding the use of thinnings in pole-size oak stands. According to European silviculturists, stands should be kept in this dense condition until age 40 or 60, to allow long, straight, clear boles to develop.

The other view, adopted, or at least practiced, by many American foresters, is that our stands should be entered as early as possible to make needed intermediate cuttings. Often these cuttings are made just as soon as enough merchantable material can be removed to carry out these operations at a break-even point or at a profit. In these early commercial thinnings, cull trees left from the previous rotation are removed, and the stand is generally put in good order—or at least as good shape as the stand permits!

Why this apparent conflict between European recommendations and our actual field practice in the eastern United States? Is it because we ignore European experience, when we know that they have raised excellent stands of oak for centuries? Actually, if we examine the situations influencing each philosophy, we find that our thinking is not in conflict. There is a place for both philosophies, each under the proper stand conditions.

Most European oak stands are far different in composition, character, and condition than our eastern American oak stands. Their stands are of seedling or seedling-sprout origin, well-stocked, and either pure or mixed with a few desirable associates. When seedling stands do not develop in this way, Euro-

pean foresters, with their more abundant and cheaper supply of labor, use a light cleaning or a series of light cleanings to make certain that the stand reaches pole-stage in relatively fine condition.

Occasionally we encounter similar high-quality stands in American forests, which have developed through some fortuitous circumstance. Where such stands occur, most American foresters are reluctant to open these stands up until full height growth has been attained. These occasional superior oak stands will yield high quantities of quality sawlogs and veneer bolts.

However, most of our oak stands are not of this high quality and give little hope of quality development without aid through silvicultural treatment. Many of our stands are of sprout origin, often 100 percent sprout. Here early removal of those stems that show the greatest tendency to develop heartwood rots from the old stump seems extremely important. In addition, our oak stands are often diverse mixtures of both desirable and less desirable oaks, heavily interspersed with low-value hardwoods that threaten to suppress and crowd out the few desirable stems. Other problems confounding the management of these stands are past ground fires, disease, uneven stocking, and vines.

Thus we feel that most of our oak stands should be molded as soon as merchantable cuttings can be made, to improve composition, eliminate the undesirable sprouts, adjust spacing, and improve bole form. Available markets in each area determine just how early this first thinning can be made; but the earlier it is carried out, the better the final stand will be. Here in West Virginia we often enter oak stands at age 25 and remove as much as one-third of the basal area per acre for pulpwood.

CLEANINGS

Forest managers often wish that they had a larger budget that would allow them to carry out cleanings in their seedling-and-sapling-stage hardwood stands. Actually the need for cleaning is often difficult to assess, and no general statement can be made that every young oak stand will benefit from a sorting over of individual stems early in the rotation. Superficially it would seem that all stands would benefit from cleaning, but certain recent evidence indicates that in many oak stands desirable changes in composition and stocking take place naturally without the help of expensive cleaning operations.

GROWTH RESPONSE AFTER INTERMEDIATE CUTTINGS

Growth response is often given as the prime motive in thinning pole-size stands. Recent measurements in oak stands that have received previous partial cuttings cause us to question whether the magnitude of response for oaks, and for many other hardwoods, is as great or dramatic as we learned in our silvicultural textbooks. Perhaps much that has been written about growth response has been based on experience with southern pines and other extremely responsive species.

An unpublished study of white oak response, conducted 8 years after a 40-year-old stand was thinned, showed no significant increase in diameter growth, regardless of the tree's vigor prior to thinning.

In another study where northern red oaks had been heavily released by selection and shelterwood cuttings, the diameter growth rate of trees on lower- and middle-third slopes showed no change during the 7 years after release. Released red oaks on upper-third slope positions had a small but significant increase in annual diameter growth. However, unreleased controls on the same site showed a small but significant decrease in diameter growth during this same period (attributed to the same amount of wood fiber being distributed over an increasingly larger girth). Thus it was concluded that there had been a small increase in wood production for oaks since the partial cuttings (fig. 1).

If we assume that response to release, in terms of diameter growth, depends initially on the tree increasing its photosynthetic surface and establishing a more extensive root system (a slow process for most oaks), then oak response in diameter growth would be a gradual process, better demonstrated by long-term studies.

We have just completed a 15-year summary of 40 one-acre research plots at the

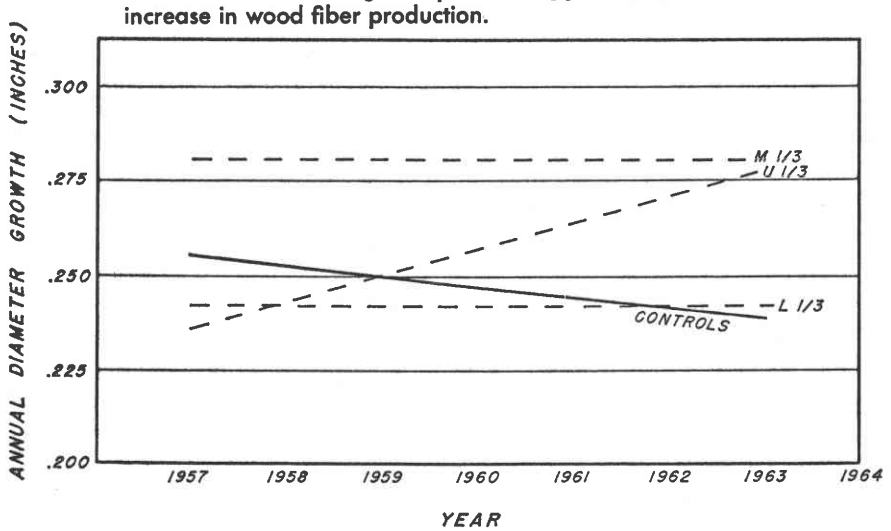
West Virginia University Forest. Twenty-four of these plots were established on oak sites. Half of these experimental areas received a cleaning during the sapling stage, at 15 years of age. This cleaning adjusted spacing, favored the better species, and removed poorly formed stems. Other plots had no cutting until 10 years later, age 25, when a commercial thinning was made. Analysis of plot data indicated that the cleaned plots had only a slight improvement in composition over the plots where the cutting, performed as a commercial operation, was delayed.

On the better oak sites, whether cleanings were used or not, yellow-poplar and northern red oak outgrew the other species and dominated the stand. Our conclusions for these good sites were that if the cleaning could be made at a profit for firewood, it was justified; however, if the cleaning had to be made at a direct cost, as an investment, then the slight improvement gained through this operation was not justified. At present, it is difficult to tell which plots had the cleanings and which had this work done later through thinnings.

On the drier oak sites, northern red, black, white, and chestnut oaks competed successfully with the less desirable species. However, where scarlet oak was abundant in young stands, its exceedingly rapid growth allowed it to crowd out more desirable oaks. Thus we felt that the cleanings on the drier oak sites were justified where scarlet oak made up a considerable percentage of the mixture, if other desirable oaks were present that could be favored. Northern red oak appeared well able to compete with all other species except scarlet oak, and automatically dominated many sites where it was originally a major component.

Cleanings may also be necessary, if the management policy favors white oak over the red oaks. In certain areas, particularly where the soils are derived from limestone, white oak of exceptional quality develops; and white oak brings a premium price. In mixed oak stands—such as the white oak—red oak—hickory type—white oak, because of its slower height growth, often falls into the lower crown classes early in the life of the stand. During the sapling stage, cleanings

Figure 1—A comparison of the diameter growth rate of the controls and the released red oaks during the period 1957-63. Although the middle- and lower-third slope oaks did not show an increase in annual diameter growth, they did not decline during this period, suggesting an annual increase in wood fiber production.



can effectively discourage the faster-growing oaks and increase the proportion of white oak permanently.

Another situation under which cleaning is often needed, and where the need is evident early in the rotation, is where mature oak stands, which had an understory of oak seedlings, were clearcut to allow this understory to form the nucleus of the new stand. If the crown canopy of the mature stand was kept tightly closed during the latter part of its rotation, the oak understory seedlings are of low vigor, and their recovery rate after exposure is slow. Low-vigor oaks are easily identified by their lack of a vigorous leader, and by their flat or umbrella-shaped tops. When low-vigor oaks make up the majority of the young stand, response to release is slow, often requiring 3 to 5 years.

Our studies, however, showed that most low-vigor oaks will recover a good growth rate. During this recovery period, red maple, sassafras, blackgum, black locust, and various shrubs and small trees may grow rapidly and resuppress these oaks before they have regained a competitive growth rate. Many of our stands of poor species, occupying former oak areas, have gained control of the site in this manner. A well-timed cleaning can often mold the composition on such sites and assure that oak will dominate the next crop.

EPICORMIC BRANCHING

Most hardwood foresters are concerned about epicormic branching. This condition appears to be stimulated after opening the stand through intermediate cuttings, particularly after thinning. Often epicormic branching is given as the reason for withholding thinnings. In extremely high-quality stands, I agree that this is a valid reason for delaying thinnings for many years—at least until late in the rotation, when the defect caused by these branches will occur only in the superficial wood.

Many recommendations have been made about how to reduce epicormic branching after thinning. Hardwood thinning patterns that leave only strong upper-crown-class trees are favored. Certain species are known to be especially prone to epicormic branching; and when thinning, where a choice of species is possible, often those known to produce the most epicormic branches are removed. Light thinnings and low thinnings have been favored, because there seems to be a direct correlation between thinning intensity, crown disturbance, and epicormic branching.

Recently, genetic differences have been identified as a major factor in determining the number of epicormic branches produced after thinning. Evidently within a species some individuals have a proclivity for producing epicormic branches, while others produce few or none. Most trees that feather out heavily after thinning give some indication of this tendency in the number of epicormic branches present on the bole before the stand is opened up.

During the past few years I have used the number of epicormic branches on the bole as a guide in marking in pole-size oak stands, to determine which trees to leave and which to cut. Observations after cutting seem to support this method of restricting epicormic production. Trees with no epicormic branches before cutting generally have few after cutting, and these few shoots are restricted to the area immediately below the crown. Those oaks that have many epicormic branches before cutting feather out very heavily after exposure, and these branches are distributed over a great length of the bole.

Epicormic branching evidently cannot be eliminated entirely, but whether to withhold intermediate cuttings for this reason seems to be clearly a question of choosing the lesser of two evils. If the thinning will generally improve the composition and form of the remaining trees, and will yield sufficient income to offset the degrading effect from "controlled" epicormic branching, then thinning must be considered the lesser of two evils.

LIBERATION CUTTING

One intermediate cutting that should play a more prominent role in oak management—and one that costs relatively little yet can have a profound effect on the development

of the new stand—is liberation cutting. Old cull trees left from previous logging operations often tower above our young second-growth oak stands. With each passing year these standards expand their crowns and do increasing damage to the developing stand beneath. With our presently available herbicides, these cull trees can be removed easily and inexpensively.

The tree injector offers the most promise for this work, because injecting does not weaken the tree at the point where the herbicide is applied. Injected trees rarely break off at the point of injection. Trees treated in this way remain standing after death and disintegrate gradually on the stump, causing little or no damage to the young stand beneath, as the twigs, limbs, and finally the bole come down piecemeal. Of all the intermediate cutting, it appears that more good can be done throughout a forest with judicious investment of limited funds for liberation cutting, than from any other improvement operation.

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STOCKING, GROWTH, AND YIELD OF OAK STANDS

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ABSTRACT. An appraisal of stocking in even-aged upland oak stands is a prerequisite for determining the cultural needs of a given stand. Most oak stands have sufficient stocking to utilize the site, but are deficient in high-quality trees. Thinning such stands offers a good opportunity to upgrade the relative quality of the growing stock and enhance the growth and yield potential. The physical yields of timber products from thinning are greatest when thinning is begun at an early age. Thinnings should be made from below at 10- to 15-year intervals.

THE BASIC CONCEPT of a forest as a renewable resource capable of producing a continuous supply of products depends on the ability of the forest to grow. Consequently the planning of forest-management activities depends on our ability to appraise stocking and to predict growth and yield.

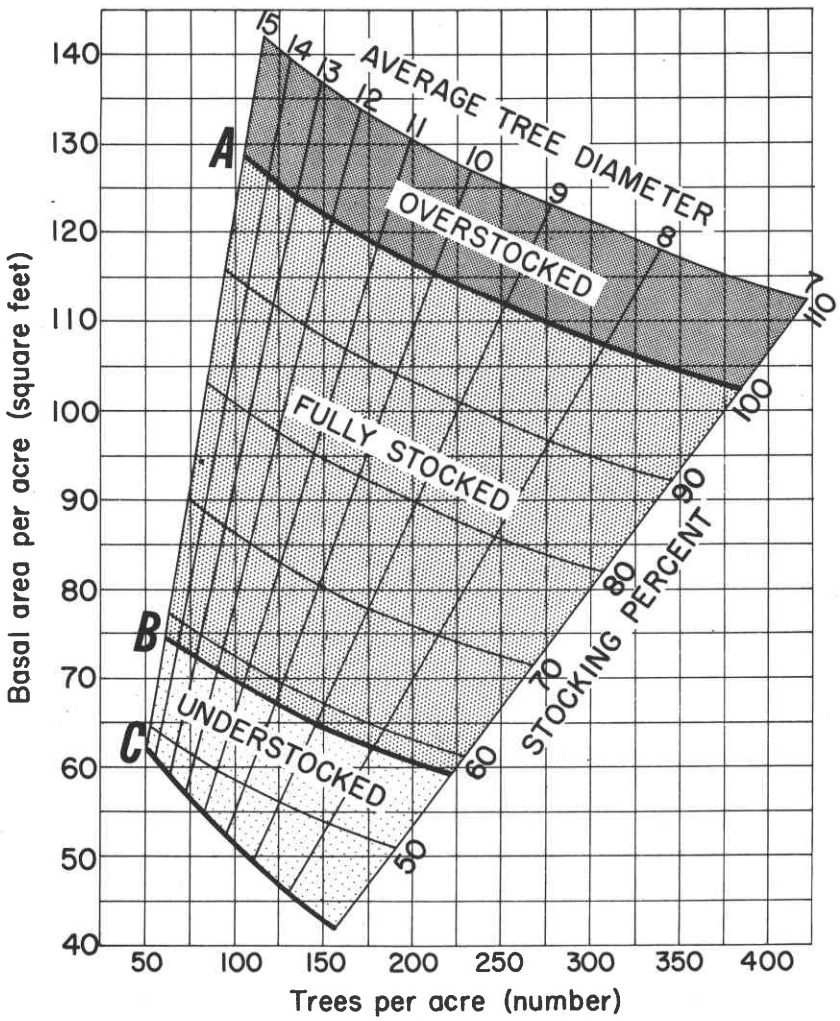
Until recently there was very little published information about the stocking, growth, and yield of oak stands. Schnur's *(1937)* yield tables, developed from normal unthinned stands, were the principal source of information about oaks. However, since 1960 some new information has become available that deals with fundamental relationships of the stocking, growth, and yield of oak stands. This information will be summarized in this paper together with new information from our research in even-aged upland oak stands.

The oak-hickory forest type comprises more than 100 million acres of commercial forest land, or nearly one-fourth of the commercial forest land in the United States *(USDA Forest Service 1958)*. Although many important species are components of this broad type, the predominant species are oaks. A description of average conditions of this broad type is of little value except in a general way. Most of the oak stands are less than 100 years old, are even-aged, and generally are overstocked with trees and understocked with high-quality stems. Seventy-four percent of the trees in eastern hardwood forests have been classified as low-grade or cull *(USDA Forest Service 1958)*.

STOCKING

Stocking can be specified in terms of either site occupancy or growth. A stand is considered fully stocked when the trees utilize the available growing space. In this respect most even-aged upland oak stands are fully stocked. Regardless of the system

Figure 1.—Relation of basal area, number of trees, and average tree diameter to stocking percent for upland central hardwoods. Tree-diameter range 7-15 (left) and 3-7 (right).

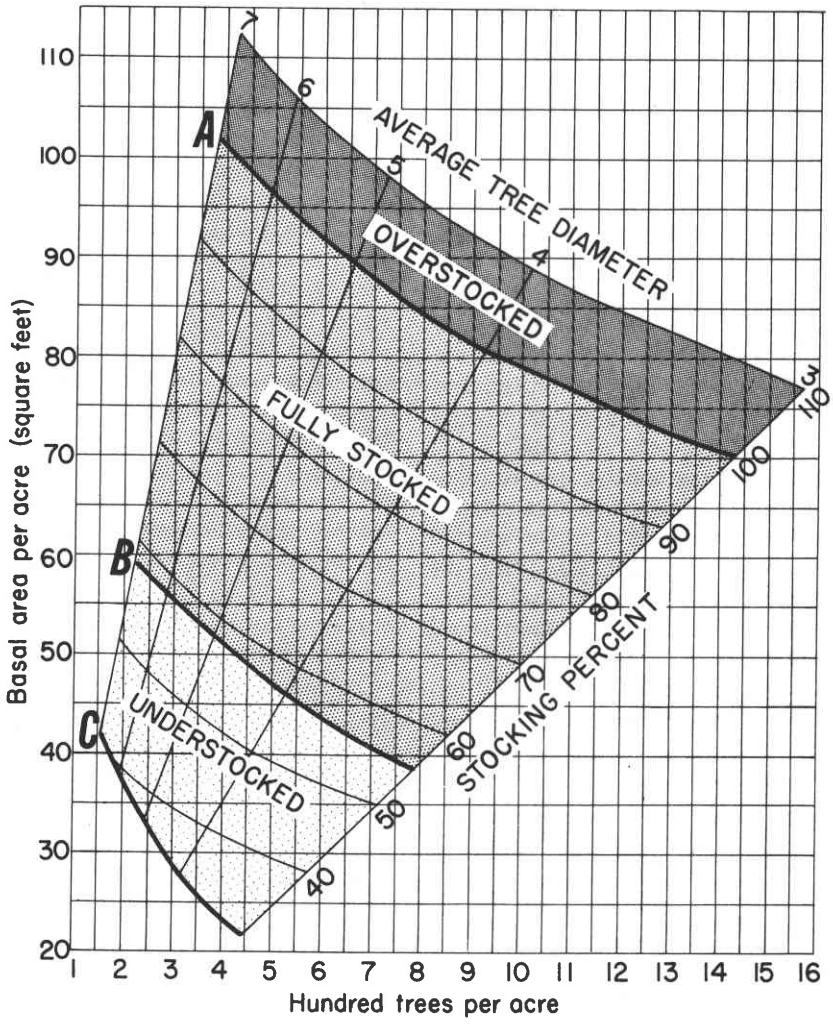


of cutting used or the abuse that a stand undergoes, some assortment of trees quickly occupies the site. The quality of the stocking may be poor in terms of desired species, stand structure, and growth; but nevertheless the site would have to be considered fully occupied.

The processes of natural mortality cause overstocked stands to seek a point of equilibrium that permits better site occupancy of the residual stand. On the other hand, understocked stands quickly reach a point of full site occupancy because natural mortality is low and individual tree growth is high. Unless oak stands are severely damaged by fire, heavy grazing, or insects and disease, they remain in a fully stocked condition. Even heavy cutting will not keep a stand from eventually reaching a fully stocked condition. Actually, from a growth and yield standpoint, overstocking may be more serious than understocking in upland oak stands.

Thus if stocking is based only on the site being occupied by trees, most oak stands would have to be considered fully stocked.

The area between curves A and B indicates the range of stocking where trees can fully utilize the site. Curve C shows the lower limit of stocking necessary to reach the B level in 10 years on average sites. (Average tree diameter is the diameter of the tree of average basal area.)



But growth and yield depend on the type and quality of trees that comprise the stocking. In this respect most oak stands are under-stocked. A living cull tree of a given diameter will utilize the same amount of growing space and offer the same competition as a desirable tree. To remove such trees might temporarily leave the stand understocked in terms of site occupancy. To leave such trees affects the growth potential and yield of the stand. This is the present dilemma about stocking of the oak forests.

Stocking standards have been established for oak stands. These standards define the range of stocking within which the growing space is fully utilized. The upper range of stocking was determined from a study of fully stocked stands that have had no record of fire, cutting, or other disturbances that would have influenced stocking. From this study we were able to determine the minimum space a tree of a given diameter needs to survive.

The lower range of stocking was determined from a study of open-grown trees where competition was not a factor in the

site. Favoring this type of tree in the thinning will produce higher volume growth returns.

Our research has shown that the quality of the site as measured by site index has only a minor effect on the diameter growth rate of oaks. Within the upland oak species there are differences in diameter growth rates. Scarlet oak and northern red oak are the fastest growers, black oak is intermediate, and northern white and chestnut are the slowest. Also, there are strong species-site interactions in which the faster growing oaks are more predominant on the higher quality sites. This relationship, together with the influence of site quality on tree height, is the major factor that contributes to the higher volume growth and yield on good sites.

BASAL AREA GROWTH

Basal-area growth in even-aged upland oak stands varies greatly with stand age. In young stands less than 20 years of age net basal-area growth per acre will average about 4 square feet per acre per year. As stand age increases, net basal-area growth decreases. At age 70, net basal-area growth per acre per year is less than 1 square foot. Estimates of net basal-area growth are useful in establishing the optimum stocking for maximum growth and site utilization. Table 3 shows the relationship of net basal-area growth to stocking percent and stand age. Maximum net basal-area growth obtained between 50 and 60 percent stocking; the recommended residual stocking increases with stand age.

Our research has shown that net basal-area growth is not influenced by the quality of the site. Net basal-area growth is a function of the average tree size and the number of trees comprising the stocking. Actually, for a given stand age, net basal-area growth may be higher on a poor site than on a good site, because the stocking on the poor site is made up of more trees of a smaller average diameter than the stocking on a good site at the same age.

YIELD

Yield from a forest is generally expressed in terms of products or volumes that can be harvested. The possibilities of producing different kinds and amounts of products are so great that they cannot be fully discussed here. Physical yields from cultural operations in forest management depend on the stand age when thinning begins, the thinning policy used, the quality of the site, and the management objectives. The feasibility of any cultural operation is generally determined by an investment analysis.

The results of one of our growth-and-yield studies involving a planned series of thinnings at a 10-year interval have been recently published *(Gingrich 1971)*. The study showed that one of the most important factors to consider when managing for maximum timber production is the stand age when thinning begins. The yield increase in cubic-foot volume and standard cords when thinning is begun at age 10 is more than 50 percent greater than the yields when thinning is begun at age 60. The latest age to begin thinning, for any significant

Table 3.—*Net basal-area growth per acre per year for even-aged upland oak stands by stocking percent and stand age, in square feet.*

Stand age (years)	Stocking percent								
	20	30	40	50	60	70	80	90	100
20	2.50	2.95	3.15	3.25	3.20	3.10	2.90	2.70	2.40
30	2.15	2.70	2.90	3.00	2.95	2.85	2.60	2.30	1.90
40	1.75	2.20	2.50	2.60	2.55	2.40	2.10	1.75	1.25
50	1.25	1.55	1.80	1.90	1.95	1.80	1.60	1.25	.75
60	.90	1.05	1.15	1.20	1.20	1.10	1.00	.80	.45
70	.50	.65	.80	.85	.90	.85	.70	.55	.35
80	.25	.45	.60	.65	.70	.65	.55	.40	.20

pulpwood production, is between 30 and 40 years, and for sawtimber between 50 and 60 years.

Yields for even-aged upland oak stands are shown in table 4. On all sites, the yield increase from stands that were thinned to a residual stocking of 60 percent at a 10-year interval was at least 25 percent greater than the yield from unthinned stands. In many cases the yield increase was much greater. The cord volume removed by thinning alone is more than 50 percent of the total yield of unthinned stands. The same is true for board-foot volume on the better sites. The cumulative cord yields (34.0) for site 55 when thinning is begun at age 20 are about equal to the normal yields (33.3) from unthinned stands on site 65. The board-foot yield from thinning increases as the site quality increases.

Table 5 is an example of how yield information can be used to obtain silvicultural recommendations. The best option is selected on the basis of the greatest cumulative yield for each site, stand age, and management period. These data show the desirability of early thinnings for all sites where maximum timber production is the objective. In the 40-year management period, the best option for board-foot production is to start thinning on all sites. When pulpwood production is the objective, the best option for stands 40 years and older is to regenerate and thin.

However, for the shorter 20-year management period there are generally two or three options that will produce similar yields, particularly on sites 65 and 75 for stands 30 years and older. Factors other than physical yields may have to be considered in making a decision. However, when a 10-year management period is used in stands that are 30 years and older and never have been thinned, the best option, especially for pulpwood yields, is often to leave stand alone.

These comparisons have ignored economic factors. However, except for this, the recommendations apply to even-aged upland oak stands that are thinned at 10- to

Table 4.—*Yields per acre for even-aged upland oak stands. A comparison of cumulative yields for a 50-year management period when thinnings are started at different ages. Thinning interval = 10 years.*

Stand age when thinning begins (years)	Cumulative yields[1] 50 years later		Volume removed by thinning during period		Yields without thinning	
	Cords[2]	*Bd. ft.*[3]	*Cords*[2]	*Bd. ft.*[3]	*Cords*[2]	*Bd. ft.*[3]
			SITE INDEX 55			
20	34.0	7,350	14.0	1,540	24.4	2,800 (age 70)
40	41.4	11,880	16.6	2,700	26.5	7,000 (age 90)
60	41.8	11,550	19.2	2,970	28.4	8,900 (age 110)
			SITE INDEX 65			
20	42.0	12,600	17.8	3,570	33.3	7,200 (age 70)
40	48.2	14,580	21.6	3,870	37.6	9,100 (age 90)
60	52.2	17,380	25.6	5,610	40.9	10,600 (age 110)
			SITE INDEX 75			
20	57.4	19,880	25.9	6,160	43.0	11,200 (age 70)
40	63.4	24,120	29.7	8,280	49.2	13,400 (age 90)
60	62.7	22,550	29.7	9,020	51.0	14,100 (age 110)

[1] Yields from thinnings + residual stand at end of period.
[2] Includes all trees 4.6 inches in diameter and larger, to a 4-inch top, inside bark.
[3] Includes all trees 10.6 inches in diameter and larger, to an 8.5 inch top, outside bark (International ¼-inch Log Rule).

15-year intervals with a residual stocking of 60 percent, and where maximum timber production is the objective.

SUMMARY

After more than 20 years of USDA Forest Service research on the growth and yield of upland oak forests, we can now confidently make recommendations for the management and culture of oak stands based on the physical yields of timber products.

Whether to thin or not depends on many factors. Most even-aged upland oak stands are overstocked for best growth and yield but are understocked with desirable high-quality trees. Thinning offers a good opportunity for upgrading the quality of the residual stand while at the same time enhancing the growth potential.

The following general thinning guides are applicable to most even-aged upland oak stands:

1. Early thinnings will yield a higher volume return than thinnings that are made in older stands. However, many early thinnings will remove unmerchantable material, and the costs involved must be weighed against the lower volume return from later thinnings.
2. In even-aged upland oak stands, greater volume yields are obtained when thinning is done from below. The dominant stand usually contains the highest vigor trees, the best stems, and the preferred species for the site.
3. A single thinning, unless followed by a planned series of thinnings at 10- to 15-year intervals, is of doubtful value. But if only one thinning is done, it will yield greatest returns, in terms of physical yields, if done at an early age.
4. Species composition does not appear to be an important factor in thinning oak stands. However, there are important species-site interactions. Small increases in yield can be expected by favoring the

Table 5.—Best silvicultural options[1] for previously unthinned stands by stand age and site, based on predicted yields in cords and board feet. Options are: (1) leave stand alone, (2) start thinning, (3) regenerate without future thinnings, and (4) regenerate with thinnings.

Stand age (years)	Site 55		Site 65		Site 75	
	Cords	*Board feet*	*Cords*	*Board feet*	*Cords*	*Board feet*
PERIOD OF MANAGEMENT: 20 YEARS						
10	2	2	2	2	2	2
20	2	2	2	2	2	2
30	2	2	2, 1	2, 1	2	2
40	2, 1	2	1, 2, 4	1, 2	2, 1	1, 2
50	2	2	2, 4, 1	1, 2	2, 1, 4	2, 1
60	2	2, 1	2, 4	2, 1	4, 2, 1	2, 1
PERIOD OF MANAGEMENT: 40 YEARS						
10	2	2	2	2	2	2
20	2	2	2	2	2	2
30	2	2	2, 4	2	2, 4	2
40	2, 4	2	4, 2	2	4, 2	2
50	4	2	4	2	4	2
60	4	2	4	2	4	2

[1] Where two or more options are listed, the physical yields are about equal.

white oak group on sites less than site index 70 and by favoring the red oak group on sites over site index 70. The performance of species other than oaks that are commonly found in upland oak stands is not definitely known except for yellow-poplar. Yellow-poplar grows as fast or faster than the associated oaks on all sites where it maintains a dominant position. Potential stem quality, spacing, and tree vigor are factors that deserve as much and perhaps even more consideration than does species when thinning even-aged oak stands.

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ECONOMIC EVALUATION OF INTERMEDIATE OPERATIONS IN OAK STANDS

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ABSTRACT. Economic evaluation of forest-management opportunities is a vital ingredient of effective forestry programs. Choices among management opportunities are necessary because opportunities inevitably exceed funds available, and they are important because opportunities commonly range from highly productive to decidedly unproductive. Economic evaluation in oak stands shows a wide range in productivity. Primary factors influencing this range include site-productivity, length of the investment period, and division of costs between private owners and public assistance programs such as the Cooperative Forest Management and Agricultural Conservation Programs.

ECONOMIC EVALUATION can be useful only if it is firmly based on adequately defined silvicultural relationships. And economic evaluation can enhance the usefulness of silvicultural and other biological knowledge. It can do this by linking silvicultural knowledge more directly to at least some of the human purposes for which forests and related resources are managed.

Economic evaluation is important for this reason, and for more specific reasons. A first specific reason relates to budgets—always an important topic and currently an unusually difficult one in many organizations. It is almost universally true that in any ranger district, woodland management work unit, or other administrative unit, there are—and always will be—many more opportunities to undertake intermediate operations or other forms of intensified management than there are funds to meet the costs. This same excess of opportunities in relation to funds also occurs at higher organizational levels.

It can be illustrated in many different ways and at many different levels. Though they involve many matters other than oak stands, estimates developed by Robert Marty and Walker Newman *(1969)* for the National Forests as a whole are particularly striking. They found that $210 million dollars could be invested in intensified timber management on the National Forests with promise of making at least a 7-percent annual return—a respectable return even in this time of high interest rates. In sharp contrast, funding for such management at the time Marty and Newman made their estimate was only $17.5 million per year. Thus it would take nearly 15 years to carry out current opportunities, to say nothing of new opportunities that would develop over this period in response to new markets, new

technology, and changes in the composition of the forest resource. Though specifics would differ, the same would be true in more restricted situations involving smaller administrative units, or a single forest type such as oak stands. The essential point is that many choices among opportunities are necessary.

And these choices are important—a second specific factor making economic evaluation important. Intermediate operations (and other specific opportunities to apply intensified management) differ greatly in terms of results in relation to efforts. These differences can be illustrated at several different levels. At a national level, Marty and Newman found that rates-of-return on investments in intensified timber management on the National Forests would range from more than 15 percent per year down to zero. Comparisons for oak stands in Pennsylvania made several years ago illustrate the same point *(Webster 1960)*. Probable costs and returns from a program of intensified management of oak stands on three progressively poorer site classes were analyzed. Rates-of-return were 9 percent, 6 percent, and 1 percent. Thus returns for management in a single type range from good to wholly inadequate.

Economic evaluation is important because choices among opportunities are unavoidable, and because these choices greatly affect the results achieved in relation to efforts. Economic evaluation—used in an appropriate manner—can help forest managers to more consistently choose opportunities that promise a large measure of desirable long-range results in relation to costs and associated efforts required to carry out these opportunities.

METHODS OF ECONOMIC EVALUATION

Economic evaluation is concerned with the comparison of results in relation to efforts or inputs. Its value lies in helping managers to identify and select efficient courses of action. Implicitly, efficient courses of action are those that yield the greatest results or outputs in relation to the inputs.

In management of oak stands, many intermediate operations constitute stand improvement. Such operations involve goals or outputs that occur at some point in the future. Associated with the choice of pursuing each goal may be additional costs or returns. To provide the manager with a means of assessing the economic efficiency of given choices among the many possible choices relating to stand improvement, the economist must weight inputs and outputs according to the time at which they are expected to occur.

Two common elements in this weighting are: (1) the contribution such choices make to present net worth, and (2) the internal rate of return associated with such choices. As measures of relative efficiency among the possible stand-improvement alternatives, these two time-weighted criteria provide a basis for choice.

In some situations, either of these criteria will yield good results. In some situations these criteria will yield similar results, ranking opportunities in entirely the same order. This is most likely when there are no restrictions on movement of assets in or out of the particular organization.

The present net worth is the discounted stream of appropriately valued inputs (costs) and outputs (returns). It is measured in dollars. It reflects the impact on the present net worth of the organization that is expected to ensue from the flow of outputs and inputs associated with a particular choice. If the present net worth of the anticipated returns is greater than the present net worth of the anticipated costs, the implication is that the particular project should be undertaken.

To apply this criterion, inputs, outputs, and their values, along with the times of their occurrence, must be known. In addition, the appropriate rate of discount must be specified. The appropriate discount rate is frequently referred to as the alternative rate of return, or the rate of return that the organization could earn on its next best investment opportunity.

Unfortunately, the next best investment may be poorly defined. This is especially true in large organizations where budgets

are specified with slight emphasis on their earnings potential in many parts of the organization. Large organizations are also likely to have overall objectives that are so interrelated as to make the use of market rates of interest inappropriate even if measurable. Under these circumstances, the internal-rate-of-return approach has distinct advantages for those segments of organizations that are concerned with allocating budgets among the various alternative opportunities available.

The internal rate of return measures the rate at which an investment and its associated incomes and costs grow into a final value. As a measure of the rate of growth, the internal rate of return is most frequently expressed as an interest rate. The internal rate of return is calculated by determining the rate of interest that would equate the time streams of the various costs and returns (initial, intermediate, and final) if all are discounted to the present. The application of the method implies that there is one interest rate that is appropriate for money received in returns and money borrowed to defray costs; but, in view of the difficulties of the alternatives, this assumption is not too difficult to surmount.

Generally, application of this criterion involves a ranking of the various alternatives in terms of the internal rate of return. Those alternatives with the higher rate of growth are to be preferred to those with a lower rate of growth. The budgets available are then allocated sequentially, beginning with those with the higher rates of return. When investments must be made in discrete segments, due consideration must be given to the size of the investment.

To efficiently choose among the various possible intermediate stand treatments on the criteria of either present net worth or internal rate of return, distinct types of information are needed:

1. The cost of choosing to carry out each particular choice.
2. The change in quality, amount, and timing of the biological response attributable to each particular choice in terms of output that the manager seeks to maximize—for example, additional cords or board feet.
3. The appropriate value measures, generally at some future time, that are to apply to the change in biological response.

In assessing the information needs, the emphasis should be placed upon the added cost and added biological response, appropriately valued, rather than upon the total cost and total biological response. It is with the additional inputs and their commensurate outputs that decisions are concerned. This is especially clear in intermediate operations, where the obvious impact of any decision is to modify the currently anticipated outcome.

Among the decisions to be made, a distinction should be drawn between those that relate to choices in a particular stand and those that relate to choices between stands. If the choice of one alternative, say thinning to 60 square feet of basal area, precludes another choice, say thinning to some other intensity as measured by basal area, then these two choices should not be considered in the same ranking of opportunities because they cannot physically be carried out on the same stand at the same time. It is much more likely that one opportunity will preclude another on choices within a particular stand than in choices where several stands are involved. Choices where one course of action does preclude another require particularly careful selection of a criterion. It is here that present net worth will frequently be preferable to internal rate of return—despite difficulties of actually using present net worth. This is true for a simple reason: a lower *rate* of return, but a larger *absolute* return, will often be preferable when a direct choice must be made. This can occur, for example, when relatively small investments in managing an existing stand are compared with larger investments involved in converting that stand to more valuable species.

Economic analysis helps the decision-maker to choose efficient courses of action. Inputs and outputs are weighted to reflect their occurrence at different times. The typical means of weighting the costs and outcomes of forest operations are the present-net-worth method and the internal-rate-of-return method. For most intermediate

operations, especially in large organizations, the internal rate of return is an appropriate means of weighting the inputs and outputs. Decisions based on either criteria should emphasize the incremental changes that result from a choice. Particular care should be taken to avoid including within the same ranking choices that preclude one another. Application of either of the time-weighting methods, or for that matter any managerial decision, requires information in terms of the cost, physical response, and value associated with each choice.

COMPARING OAK MANAGEMENT OPPORTUNITIES

Several analyses have been made using these methods of economic evaluation to directly compare oak management alternatives. These analyses have been directed primarily toward intermediate operations. We will draw primarily on three such analyses.

Marty and Newman *(1969)* analyzed opportunities for intensification of timber management on the National Forests as a whole. The oak-hickory type was one of those explicitly considered. "Package programs", involving several management practices, were evaluated for oak-hickory (as for other types) on each of several site-productivity classes. Webster *(1960)* evaluated management opportunities that were applicable in a specific but sizable geographic area, namely Pennsylvania. Separate evaluations were made for individual practices that are applicable at different stages in stand development. Manthy *(1970)* carried analysis further for essentially the same area and practices considered by Webster. He analyzed these practices as parts of the Cooperative Forest Management and Agricultural Conservation Programs. He made separate calculations of investment returns to the landowner and to the agencies administering these public programs.

Rates of return that were calculated in these three analyses are shown in tables 1 to 4. These rates measure return on additional investment needed to carry out the specified practices.

We might note several items concerning these rates of return. First, we see that re-

Table 1.—*Rates of return for selected intermediate operation and reforestation opportunities on the National Forests*

Timber type group	Site-productivity class	Intensification rate of return
		Percent
RELEASE AND PRECOMMERCIAL THINNING OPPORTUNITIES		
Oak-hickory	1	8.2
	2	7.0
	3	3.6
	4	3.0
Maple-beech-birch	1	(1)
	2	6.4
	3	4.0
REFORESTATION OPPORTUNITIES		
Red-white pine	1	10.0
	2	8.8
	3	7.8
	4	5.9
Fir-spruce (eastern)	1	(1)
	2	6.7
	3	5.5

Source: Marty and Newman *(1969)*.
[1] No estimate.

Table 2.—*Return on additional investment in timber-management practices in Pennsylvania*

Management opportunity	Rate of return compound interest
	Percent
OAK	
Thin poletimber, site 1	8.6
2	6.8
3	1.1
Clean seedlings & saplings, site 1	6.0
2	4.7
3	(1)
NORTHERN HARDWOODS	
Thin poletimber, site 1	11.2
2	10.3
Clean seedlings & saplings, site 1	7.8
2	7.2
COVE HARDWOODS	
Thin poletimber, site 1	12.0
2	9.8
SOFTWOODS	
Plant bare land, site 1	5.3
2	4.6
3	2.3

Source: Webster *(1960)*.
[1] No estimate.

Table 3.—*Summary of potential financial yields of ACP-CFM-supported plantings at financial maturity and for TSI practices for public, private, and total establishment investments, by site-productivity class.*

[In percent, compound interest]

Practice	Site I	Site II	Site III
PUBLIC INVESTMENT			
Planting:			
White pine	[1]6.9- 8.2	5.8- 7.0	3.1- 3.9
Red pine	7.3- 9.3	6.7- 7.6	6.1- 6.9
Larch	8.9- 9.4	7.3- 7.7	5.6- 5.9
Norway spruce	7.8- 9.0	5.8- 6.5	—
Cleaning and liberation:			
Oak	5.4	4.1	1.0
Northern hardwoods	7.3	6.3	—
Thinning:			
Oak	7.9	6.0	1.0
Northern hardwoods	11.1	10.2	—
Cove hardwoods	12.2	9.9	—
PRIVATE INVESTMENT			
Planting:			
White pine	11.5-12.9	9.6-10.8	4.8- 5.7
Red pine	12.8-14.1	11.9-13.2	10.6-11.6
Larch	15.5-17.6	13.2-13.7	9.6- 9.9
Norway spruce	15.9-17-1	10.6-11.3	—
Cleaning and liberation:			
Oak	8.3	7.1	3.2
Northern hardwoods	10.3	9.7	—
Thinning:			
Oak	12.1	10.2	4.4
Northern hardwoods	16.7	15.7	—
Cove hardwoods	18.0	15.5	—
TOTAL INVESTMENT			
Planting:			
White pine	6.6- 7.9	5.6- 6.8	2.9- 3.8
Red pine	7.1- 8.0	6.5- 7.4	5.9- 6.8
Larch	8.6- 9.0	7.9- 7.4	5.4- 5.7
Norway spruce	7.4- 8.6	5.5- 6.2	—
Cleaning and liberation:			
Oak	5.1	3.7	1.0
Northern hardwoods	7.0	5.9	—
Thinning:			
Oak	7.4	5.4	1.0
Northern hardwoods	10.5	9.5	—
Cove hardwoods	11.7	9.2	—

[1] The high and low interest rates for planting are rates earned under the high-and low-stumpage price assumptions.

Source: Manthy *(1970)*.

Table 4.—*Summary of potential financial yelds of CFM-supported plantings at financial maturity and for TSI practices for public, private and total establishment investments, by site-productivity class.*

[In percent, compound interest]

Practice	Site I	Site II	Site III
PUBLIC INVESTMENT			
Planting:			
White pine	[1]8.3- 9.6	7.0- 8.2	3.9- 4.8
Red pine	8.9- 9.9	8.2- 9.2	7.4- 8.2
Larch	11.3-11.8	9.1- 9.5	6.8- 7.1
Norway spruce	10.2-11.4	7.2- 7.9	—
Cleaning and liberation:			
Oak	7.2	5.9	1.6
Northern hardwoods	9.2	8.4	—
Thinning:			
Oak	10.4	1.0	2.7
Northern hardwoods	14.5	13.5	—
Cove hardwoods	15.8	13.3	—
PRIVATE INVESTMENT			
Planting:			
White pine	7.5- 8.8	6.3- 7.5	3.4- 4.3
Red pine	8.0- 9.0	7.3- 8.3	6.6- 7.5
Larch	9.9-10.4	8.1- 8.5	6.1- 6.4
Norway spruce	9.8-10.0	6.4- 7.1	—
Cleaning and liberation:			
Oak	6.0	4.7	1.0
Northern hardwoods	7.9	7.0	—
Thinning:			
Oak	8.6	11.8	1.0
Northern hardwoods	12.1	11.2	—
Cove hardwoods	13.4	10.9	—
TOTAL INVESTMENT			
Planting:			
White pine	6.3- 7.6	5.4- 6.5	2.9- 3.6
Red pine	6.7- 7.7	6.2- 7.1	5.6- 6.2
Larch	8.2- 8.5	6.6- 7.1	5.1- 5.4
Norway spruce	6.9- 8.0	5.2- 5.9	—
Cleaning and liberation:			
Oak	5.2	3.9	1.0
Northern hardwoods	6.7	6.1	—
Thinning:			
Oak	7.5	5.6	1.0
Northern hardwoods	10.7	9.7	—
Cove hardwoods	11.9	9.4	—

[1] The high and low interest rates for planting are rates earned under the high-and low-stumpage price assumptions.

Source: Manthy *(1970)*.

turns range from approximately 12 percent per year down to essentially zero. This range is related to a considerable number of factors. It will be useful to examine these factors individually to the extent that available data permit.

Site productivity affects economic returns very sharply. The specific numbers differ from one analysis to another. The fact that Marty and Newman *(1969)* used a different measure of site productivity that did Webster *(1960)* and Manthy *(1970)* also complicates matters. Nevertheless, there are important common threads:

- With three broad site-productivity classes, the rate of return on investment in various intermediate operations is 5 to 8 or 9 *times* as great in stands in the top sites as on the poorest sites.
- The absolute difference between rates of return on best vs. poorest sites is consistently 4 to 7 percent annually over a range of specific practices and particular sources of information.
- Except under unusual circumstances, it seems unlikely that intermediate operations will fully pay for themselves (all costs considered) in stands below site index 60 (site 2) even if a fairly modest return is acceptable; and agencies or investors concerned with a moderately high level of efficiency in use of their budget dollars will find few opportunities attractive on site indexes lower than 80 (site 1).

All these common threads point the same direction: site productivity must be recognized as a crucial factor in choosing oak stands in which intermediate operations are to be carried out. In applying this, we should of course recognize that factors other than biological productivity may also contribute to the "goodness" of some sites and the "badness" of others. Proximity to markets, to transportation, and to concentrations of recreationists are obvious examples. Nevertheless biological productivity is extremely important.

The period between expenditure and returns—technically the "investment period"—also has a substantial effect on returns. Long investment periods reduce returns. Look closely at the analyses by Webster *(1960)* and Manthy *(1970)*. Rates of return for management that begins with thinning in 35-to-40-year-old stands are consistently 2 or 3 percent per year higher than those for management beginning with cleaning and liberation in 10-to-15-year-old stands. This runs counter to our urge to concentrate intermediate operations in young stands where more can be accomplished. It is true that more can be accomplished, but scarce funds are kept tied up much longer. This prevents uses of these same funds to carry out other desirable practices. The sense of the matter is as follows:

> Management regimes requiring heavy expenditure early in the rotation face a major cost disadvantage in comparison with those concentrating expenditure toward the end of the rotation. Therefore there is strong reason to favor a management program that concentrates expenditures toward the end of the rotation, if it will achieve the desired result. This argument applies even if somewhat larger expenditures are required later. For example, a 10-year delay in any management operation will increase profitability even if the cost increases by approximately one half, in most cases. (*Webster and Marty 1966*).

Cost sharing (of the type available to private landowners under the Agriculture Conservation Program) raises the return the owner receives on *his* investment in intermediate operations. This is true even though returns on overall investment are not affected. ACP currently pays on an average of 80 percent of the private owner's costs of carrying out approved practices. These costs are simply shifted from the owner to the administering agency. Manthy *(1970)* found that such cost-sharing increased returns to such private landowners an average of approximately 4 percent per year over returns otherwise obtainable. This 4 percent difference would, of course, change if the cost-share rate were changed, or if the overall rates of return on the practices involved were either appreciably higher or lower.

Now look beyond management of oak forests for a moment. How do oak forests compare with other associated forest types? Specifically, how do rates of return on intermediate operations compare? We will

attempt only a capsule view, even though all three analyses bear on this point. So many comparisons could be made that it is difficult to go very far without becoming inundated in data. The analyses concerned with management opportunities in Pennsylvania indicate that returns on intermediate operations are somewhat lower for oak than for nothern hardwoods or cove hardwoods. On the other hand, they also indicate that intermediate operations in oak generally bring greater returns than does softwood plantation establishment in this region. These estimates of differences are partially contradicted by the analysis for the National Forests as a whole, but this may be more apparent than real. The relatively small acreage of high-site northern hardwoods in the National Forests, and relatively more optimistic assumptions about losses to fire and pests in softwood plantations, appear to be factors giving Marty and Newman *(1969)* a somewhat different ranking of opportunities.

We can use the analyses concerned with management opportunities in Pennsylvania to examine the extent of differences between forest types. We can do this even though it is difficult to generalize meaningfully. Nevertheless, it would appear that for intermediate operations on top-quality sites, northern hardwoods and cove hardwoods return an extra 2 to 4 percent annually as compared with oak. And the difference seems to be greatest for practices–like thinning in poletimber–that involve reasonably short investment periods. In contrast to top-quality sites, there is little if any difference in returns between types on relatively poor-quality sites (except for the obvious point that some of these types do not normally occur on poor sites).

ECONOMIC EVALUATION: USEFULNESS AND LIMITATIONS

The rates of return result from specific kinds of economic evaluation directly applied to intermediate operations in oak stands and associated forest types. We can also view them in broader perspective. Namely, what is the real usefulness, and what are the limitations, of economic evaluation of this kind? And how might these limits be pushed back to make this kind of analysis more useful?

Systematic analysis of this kind can help forest managers distinguish more objectively among their alternatives. Management alternatives differ greatly. It is important to distinguish among them. Doing so is the difference between resource management as a low-productivity field not likely to receive growing public and budgetary support, and resource management as a high-productivity field that will invite support.

Economic evaluation has at least three strong points.

1. It is directly oriented toward people, based on at least some of the objectives for which natural resources are managed. Therefore it suggests alternatives that are relevant.
2. It is concerned with quantitative comparisons of alternative courses of action. Thus it introduces a degree of objectivity and appeal to fact in comparing alternate courses of action.
3. Finally, economic evaluation is an integrating activity, pulling together several different kinds of knowledge. It can increase the value of silvicultural information by linking such information more directly to human objectives.

Economic evaluation also has at least four limitations. The first relates to the real objectives of forest managers. For purposes of analysis, we commonly postulate objectives that are relatively simple, well-defined, and consistent. But real objectives are frequently complex, not very well defined, and to some degree contradictory. Analyses can thus say that *if* a manager's objective is to produce additional timber values at least cost, or to create a particular environment as quickly as possible, *then* his best course of action is to do thus and so. Particular managers will have to consider how well the *if* matches their objectives and modify the *then* to take account of differences.

A second limitation relates to types of decisions. Many decisions are are concerned with methods; specifically, how best to spend a given budget? Other decisions are concerned with production goals and deter-

mination of the size of budgets. Budget decisions involve a much wider range of alternatives than do method decisions. At the highest level, public forest management may compete for funds with highway construction and expenditures for schools and mental hospitals, for example. For that reason, comparisons of costs and benefits via economic evaluation will necessarily be much less complete guides to budget decisions than they are to method decisions.

A third limitation relates to values that are not readily measurable. Recreational and watershed services are not commonly bought and sold by the unit. Economic evaluation can still contribute directly to many methods decisions. Many alternatives can be evaluated by direct comparisons of costs and physical outputs. However, nonmarket-determined values do pose a severe roadblock to budget analyses that seek to determine how much timber, water, recreation, and other forest products should be produced.

A fourth limitation relates to imperfect information. We frequently have some difficulty estimating the cost of particular management practices, considerable trouble predicting changes in physical output, and extreme difficulty in forecasting future prices or values. Three situations may occur under these circumstances. One alternative may be clearly better than the others despite imperfect information; it may have a good chance of being better; or it may be simply impossible to tell on the basis of the objective information available *(Marty 1964)*.

Efforts to increase the usefulness of economic evaluation relate closely to the quality of information that is available for use in these evaluations. Perfection vs. imperfection of information is a matter of degree.

Economic evaluation requires three types of information: costs, response, and value. Difficulties of locating high-quality information for use in economic evaluation increase in that order. Rather standard study procedures will produce accurate cost information. We have somewhat greater difficulty predicting biological responses despite 50 or 60 years of silvicultural research. And we have extreme difficulties predicting future values of products and services. Costs relate directly to actions to be taken now, so no major effort to foresee the future is required. Both physical responses and future values involve predicting events that will occur in the future. This is inherently difficult. However, prediction of biological responses is the easier of the two because biological relations are relatively stable. In contrast, future values depend substantially on people's preferences, which can change substantially in relatively short periods.

These differences in quality of information clearly indicate where efforts to improve information should be concentrated. Relatively small increases in the quality of information about use trends, utilization relationships, and other factors influencing values would greatly improve analyses of the type we have discussed—hence major efforts is called for. Improved predictions of biological responses also merit considerable effort because major improvement would seem within our grasp even though the deficiencies here are less striking than in the case of future values.

In conclusion, we would again underline the importance of economic evaluation as a means of systematically distinguishing between high-productivity management alternatives and low-productivity management alternatives. This is important for efficient production of products and services. Careful identification of high- and low-productivity management alternatives may also contribute in an important way to our forest resources in a distinctly naturalistic manner. This appears to be one of the things society is urgently demanding. Careful identification of high-productivity opportunities, and effective development of these opportunities in an intensive manner, may enable us to meet our commodity needs from a relatively modest part of our total forest land area—certainly less than would be needed with opportunities ineffectively identified and developed. Such concentration of effort would appear to us to be a major means of breaking a number of our serious resource-use conflicts. This, we think, is a major aspect of the usefulness of economic evaluation of management opportunities.

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WILDLIFE AND OAK MANAGEMENT

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ABSTRACT. General habitat values of the upland oak type are discussed. Major attention is focused on a management scheme to produce sufficient acorns for game and non-game species of acorn-consuming wildlife at optimum population levels. An estimated minimum average of 100 pounds per acre of sound fresh acorns should be produced from the tree crowns to accomplish this goal. A cutting system for an 800-acre management unit is described, based on even-aged silviculture, a 10-year cutting schedule, and an 80-year rotation. Periodic thinning in oak stands is necessary to produce the quantity of acorns required by wildlife.

MEASURES TO IMPROVE wildlife habitat are classed as either *direct* such as installation of waterholes, sod clearings, and game food plantings; or as *indirect*, where the improvement is accomplished through coordination with another resource-management activity. This paper deals only with indirect improvements brought about by coordinating wildlife needs with normal oak management in the upland oak type. Major emphasis is given to production of acorns in sufficient quantity to satisfy wildlife needs.

The oaks have special wildlife values for both cover and food. Young oaks with branches close to the ground fill a vital role during winter months because their leaves persist longer than those of most other species, and they often provide the only brushy cover in the dense pole stands that are so prevalent today in much of the oak range. Aside from the cover value of undergrowth oaks, there is evidence that dried leaves are important in the winter diet of whitetail deer. Captive deer free to range in a mixed oak forest in Pennsylvania showed a preference for dried leaves—23 percent of the diet in late fall and 36 percent in the food-scare winter months *(Watts 1964)*.

Thirty years ago it was reported that different parts of an oak tree are known to be eaten by 186 different kinds of birds and mammals, and the geographic distribution of a number of animals seems to coincide with or be dependent on the range of oaks *(Van Dersal 1940)*. Stiteler and Shrauder *(1964)* reported that the preferred species of woody browse for deer on the Jefferson National Forest in Virginia—greenbrier, sourwood, azalea, dogwood, blueberry, and chestnut—all occur more frequently in association with the oak type than in the other five forest types sampled. Periodic cuttings will encourage the growth of these preferred species.

Important as these cover and forage values are to wildlife, acorn production reigns supreme as the greatest contributor to the welfare of forest wildlife. The fol-

lowing list, far from complete, shows those birds and mammals in the Northeastern and Southeastern States reported to consume acorns to the extent of 10 to 50 percent of their diet *(Martin et al. 1951):* wood duck, ruffed grouse, wild turkey, grackle, bluejay, nuthatch, brown thrasher, red-bellied woodpecker, red-headed woodpecker, black bear, raccoon, fox squirrel, gray squirrel, and white-tailed deer.

To cite a few specific examples in relation to game species, acorns in the Ozarks of Missouri comprise 37 percent of the turkey's yearlong diet and 54 percent of the deer's diet *(Dellinger 1970).* Allen *(1943)* reported on a study in Michigan where 70 percent of the fox squirrels' diet was acorns. The gray squirrel requires 1.5 pounds of food per week *(Uhlig 1956).* If this were all provided by acorns from October through March, about 40 pounds would be needed to feed one squirrel. Ruffed grouse may turn heavily to acorns when they are abundant. Bailey et al *(1955),* in central Pennsylvania studies, found acorn fragments in 99 percent of the grouse droppings collected in October 1953; and acorns comprised an estimated 70 percent of the food volume consumed during that month. Scrub oaks provided some of these acorns.

There can be little doubt that management of wildlife habitat in the oak types should give top priority to the production of acorns to increase the feeding capacity for forest wildlife. Three questions come to mind in the acorn-wildlife relationship: (1) How much production can be expected from the different oaks by species, tree sizes, and stand densities? (2) How much acorn production is needed for different wildlife species at given population levels within a management unit? And (3) what kind of silviculture and management system can best meet these wildlife needs?

ACORN PRODUCTION

This varies not only from year to year, and from species to species, but also from tree to tree of the same species on the same site in the same year. Weather apparently has a great effect, and heredity seems to play a strong role. For wildlife-management purposes, it is necessary to deal with averages over several years and hope for the best. It is desirable to have other mast-producing species in the stand—black gum and hickory—in the event of widespread acorn failure. Also, squirrel dens are more prevalent in the non-oak species.

The number of acorns produced by each species depends on the size of the tree crown, which in turn is strongly correlated with the diameter of the trunk. From a 7-year study of five oak species in northern Georgia and western North Carolina, Downs *(1949)* provided information showing that scarlet oak is the best producer, and that production decreases in the larger diameters of white and northern red oak (table 1). He also found that only 46 percent of the acorn crop fell to the ground in sound condition. This needs to be con-

Table 1.—*Fresh acorns produced (in pounds) during an average year, for various species and sizes*

D.b.h. (inches)	Chestnut oak	White oak	Northern red oak	Black oak	Scarlet oak
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
10	0.9	0.7	0.4	1.1	2.5
12	3.0	1.4	2.2	1.7	3.9
14	5.0	2.8	5.7	2.3	5.6
16	6.0	4.5	10.0	2.8	8.0
18	8.1	6.7	14.5	3.4	12.1
22	9.8	11.3	17.1	4.6	17.5
26	10.5	13.1	13.8	5.8	18.3
30	10.8	12.5	10.0	7.0	18.3

A LOOK TO THE FUTURE

How times have changed since those early days! Many uses listed have gone completely, but others have come to take their place; and we see the pattern continue in other directions as our society and economy change.

We hope we can reverse the cynic's adage that "the only thing we learn from history is that we learn nothing from history" and resurrect some good from a look at the past. In some markets where wood has lost its place, it is perhaps better that way. In others, we and the consumer are the losers.

One development in the industrial field is laminated trailer floors, which may surpass home flooring as a market for low grades of oak. This product is now about 15 years old and is well established.

The pallet industry is growing tremendously. With the advent of the pallet exchange program, pallets are now being used for both storage and shipping.

We are entering a period of increased demand for railroad ties as the first creosoted ties begin to deteriorate. Nothing has ever been found to compete effectively with wood, and particularly oak, in this use.

Oak continues to be in demand for mine timbers, barrels, cars with price tags over $6,000, and caskets. Oak in architectural woodwork still excites the most discriminating people in the design field.

On looking into the future, we can see that the hardwood industry faces many challenges. As we enter the environmental decade, perhaps the greatest challenge we face is our responsibility toward proper stewardship of the land. We are also challenged in the market place, by products wanting to make believe they are wood. Perhaps some will find their place; but hopefully Mrs. Housewife will always say, "I love the feel of real wood." This is not only a response to the physical touch of wood, but a response to the feeling of quality and sturdiness that wood brings.

Oak lumber is also being challenged by the wood fiber industry. Is the day coming when the future of wood is all in fiber? Will everything made of wood be from a tree that has been taken apart cell by cell and put back together again? Will trees be harvested entirely by giant combines, ground up on the spot and blown to mills? Perhaps, but I doubt it. The warmth, beauty, character and interest created by oak lumber will always be in demand. Here in these beautiful hills of Appalachia we will continue to grow the finest oak in the land, for use as lumber.

Forest Survey figures show that we had some 50 billion board feet of sawtimber in the mountains in 1950 *(Wray 1952, Ferguson 1964)*. Today the survey shows we have some 32 billion board feet. Of this volume, 18 percent is in oak. The figures indicate that overall volume is increasing,

Table 1.—*Estimated volume of Appalachian hardwood and oak production, 1970 and 1980*

Product	1970 production	Forecast 1980	Percent oak
	Million bd. ft.	*Million bd. ft.*	*Percent*
Furniture	590	750	30
Flooring	170	170	95
Architectural woodwork	80	90	75
Pallets & containers	250	500	60
Industrial uses*	310	500	50
Total	1,400	2,010	—

Sources: Baumeister *(1965)*, Wallin and Strobel *(1969)*.
* Ties, laminated trailer floors, mine timber, etc.

and with it the volume of oak is increasing. Also, the larger size trees are keeping pace.

We will continue to harvest and manage our timber so that game, water, and recreation can be part of our life. And through such management, we will continue to provide a living, growing, multiple-use forest that will provide the homemaker with the warmth, beauty, interest, and character of oak, knowing full well that when she looks at her surroundings she can say, "By using this wood I am helping to make a better world for my children to inherit."

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PREDICTING YIELDS FROM APPALACHIAN RED OAK LOGS AND LUMBER

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ABSTRACT. One utilization problem is in pinpointing how to efficiently and effectively recover usable parts from logs, bolts, and lumber. Yields, which are output divided by input, provide a key to managers who make processing decisions. Research results are applied to indicate yields of graded lumber and dimension stock from graded Appalachian red oak (group) logs. How to calculate yields is shown. Managers may use these applications for developing processing alternatives.

THE WOOD-PROCESSING industry in the United States is about 350 years old. At the turn of the century, raw material was plentiful, cheap, and of good quality. Manpower to process wood was also plentiful and cheap. Profits were up even though, as Scribner *(1914)* warned, "the so-called waste stock is often the measurement of profit or loss in a mill or factory."

Now skilled labor is critically scarce; and labor, equipment, capital and transportation are expensive. Our hardwood supply is adequate, but the trees of desirable species and good quality are not sufficiently available for our increased needs. Furthermore, stumpage, log, and lumber prices are rising, causing a profit squeeze.

Moser *(1967)* spoke for modern scientific processors when he said, "A savings of one percent of raw material (yield) is equal to a savings of ten percent of labor to process the raw material." His statement points out the difference between processors of the past and present. Progressive processors of today speak in terms of "yield" rather than "waste", and they quantify yield knowledge. This, coupled with cost data, helps them avert a profit squeeze.

To be knowledgeable about yields, process planners must know, by volume and quality, their raw-material inputs and their product outputs. For example, a sawmill manager must know the scale, by grades and species, of his logs (inputs) and the volume, by grades and species, of his lumber (output). A dimension-plant manager must know his lumber volumes by grade and species (input), as well as his dimension-stock volumes by grades (output). With these data they can calculate yield percentages by dividing the output by the input.

The ability to predict yields gives planners alternatives on which to make production decisions. With other production data, yield

predictions can be applied before the product is produced. Some of these applications follow:

1. Determine raw-material requirements based on product purchase orders.
2. Determine raw-material grade mixes based on product requirements.
3. Estimate raw-material and processing costs.
4. Pinpoint needed lead time from the customer's shipping date back to the raw-material purchase date.
5. Schedule production to meet shipping dates.
6. Check on effectiveness of machines and operators.
7. Develop product values and prices more accurately.
8. Use these data in feasibility studies.

On the other hand, many sawmill and rough mill managers have neither the time nor the talent to develop yield data. To assist them, USDA Forest Service research results are available that give general yield data. The purpose of this paper is to make a small part of the general results more specific. Thus yield data may be used by processors who make lumber and dimension stock from Appalachian red oak (group) logs.

THE PROCESSES

Definitions

A "process" is a series of operations through which a raw material flows to arrive at a product. An "operation" is that part of a process that is accomplished at one work station or by an individual, without radically changing his equipment or work-place arrangement. Furthermore, wood-quality categories, which are identified by grades and specifications, permit the best utilization of the raw material during the process.

To study processes, one must first define the end products. Lumber and dimension stock are chosen as products for discussion for this paper.

Sawmill Process Yields

To develop lumber yields in a sawmill, log data are recorded by the log scaler. Pertinent data needed for each log are species, diameter, net scale (either International ¼-inch or Scribner Decimal C log rules), and grade *(Ostrander et al. 1965)*. By species and log grade, these data are summarized on separate sheets of columnar paper (table 1).

After diameter, number of logs, and net log scale are listed in their respective columns, the dry-lumber volumes are calculated for each diameter class, using tables from Vaughn et al. *(1966)*. That is, multiply net log scale by the plus or minus overrun figure

Table 1.—*Form for calculating lumber yields*[1]

Log diam.	Logs	Net log scale[2]	Overrun (±)	Dry lumber volume	Lumber volume by grades					
					FAS	Sel.	No. 1 Com.	No. 2 Com.	No. 3A Com.	No. 4B Com.
In.	*No.*	*Bf.*	*Pct.*	*Bf.*	*Bf.*	*Bf.*	*Bf.*	*Bf.*	*Bf.*	*Bf.*
13	33	2,904	2.8	2,985	585	385	776	412	266	519
14	20	2,200	5.1	2,312	812	305	509	294	178	215
27	1	448	−0.6	445	248	35	53	10	43	56
Total	203	33,447	—	33,809	11,809	3,330	9,144	3,620	1,806	3,644
Percent of net log scale			—	—	35.3	10.0	27.3	10.8	5.4	10.9

[1] Example yields are from grade 1 red oak (group) logs.
[2] International ¼-inch log rule.

obtained from this publication. After adding to or subtracting from net log scale, record this in the dry-lumber volume column on the form.

Next, multiply the dry-lumber volume in each diameter class by the NHLA grade yields shown in the publication. Record these volumes under each respective grade column on the form. Finally, sum each column at the bottom of the page and calculate the percentage yields by lumber grades. This is done by dividing the total lumber volume per grade by the total net log scale and multiplying by 100. This results in the lumber yields by grades for the mix of diameters in the log sample. Then follow the same procedure for other log grades and species.

We developed lumber grade yields from a representative sample of red oak (group) logs that were delivered to Appalachian sawmills *Goho and Wysor 1970* and table 2). These may be used by Appalachian lumber producers for long-term factory-grade lumber yields. However, if not representative of a producer's log diameters, the yields should be calculated by using the techniques previously explained.

Table 2.—*Predicted air-dry lumber yields from Appalachian red oak (group) logs*
(Percent of net International log scale)

Lumber grade	U. S. Forest Service log grades		
	1	2	3
FAS	35.3	8.0	1.0
Select	10.0	5.3	0.6
No. 1. Common	27.3	32.1	16.2
No. 2 Common & SW	10.8	20.0	23.1
No. 3A Common	5.4	9.6	12.5
N. 3B Common	10.9	22.9	43.5
Total[1]	99.7	97.9	96.9

[1] May equal more than 100 percent because of overrun, as well as timbers and sound square-edge produced but not included. These are circular headsaw yields. For bandsaw yields, add 5 percent.

Rough Mill Process Yields

Prediction techniques are also available for determining dry dimension-stock yields from graded lumber. Based on cutting bills

Table 3.—*Form for calculating dimension yields*[1]

Cutting length	Volume required	Yields			Dry lumber required	Cutting volume		
		Cumulative	Adjustment	Individual		Obtained	Short	Excess
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
In.	*Bf.*	*Pct.*	*Pct.*	*Pct.*	*Bf.*	*Bf.*	*Bf.*	*Bf.*
65	100	51	0	51	196	100	0	0
40	100	65	0	14	—	27	73	0
24	100	71	0	6	—	12	88	0
16	100	73½	0	2½	—	5	95	0
Subtotal	400	—	—	73½	[2]196	144	—	—
40	73	59	0	59	124	73	0	0
16	85	71	0	71	119	85	0	0
Total	400	—	—	—	554	400	—	—

[1] Cutting bill of equal volume requirements of ¼-inch clear-one face cuttings 2 inches and wider from FAS red oak (group) lumber.

[2] Total optimum yield = $\frac{400}{554} \times 100 = 72.2$ percent of lumber required.

and purchase-order requirements, yields for different cutting lengths may be estimated from published charts in *FPL 118 (Englerth and Schumann 1969)*. The techniques are comprehensive so that yields of dimension by lengths and widths, either random or fixed, are obtainable.

To derive desired yields, use the recommended form (table 3) as an example, as follows: the volume requirements by cutting lengths shown in columns (1) and (2) are based on purchase-order requirements. Yield data entered on the form in columns (3), (4), and (5) are explained in *FPL 118*. Dividing the individual yield (51 percent) of the longest cutting in column (5) into the volume requirements (100 bf.) for the longest cutting in column (2) gives the lumber required (196 bf.) to yield the 65-inch cuttings. Then, multiply the lumber required (196 bf.) by each of the individual yield percentages in column (5), and enter these in column (7). To obtain either columns (8) or (9), subtract the volumes in column (7) from the volumes in column (2).

In most cases, succeedingly shorter cutting lengths will require additional lumber volume. So prepare another form, but transpose the shortages in column (8) to column (2). Prepare enough tables until the lumber requirements for the shortest cutting in the cutting bill are completed.

For the example shown in table 3, four tables are required. Finally sum up columns (2), (6), and (7) in a total line at the bottom of the form. After the total in column (7) is divided by the total in column (6) and multiplied by 100, total optimum yield is obtained.

By using the same cutting bill, other tables may be prepared for yields from the other lumber grades and grade mixes. These yields are shown in table 4.

Table 4.—*Predicted dimension yields from kiln-dried 4/4-inch Appalachian red oak (group) lumber*[1]
(Percent of dry lumber volume)

Lumber grade	Grade mix	Dimension yields
FAS	100.0	72.2
Select	100.0	68.6
FAS	25.0	
Select	25.0	67.8
No 1 Common	50.0	
No. 1 Common	100.0	66.3
FAS	29.5	
No. 2 Common	70.5	60.2
No. 1 Common	47.8	
No. 2 Common	52.2	60.3
No. 2 Common[2]	100.0	54.9
No. 3A Common[3]	100.0	38.8

[1] See cutting bill in table 3.

[2] Cannot yield appreciable volume of 65-inch-long cuttings.

[3] Cannot yield appreciable volume of 65- and 40-inch-long cuttings.

Table 5.—*Predicted dimension yields from Appalachian red oak (group) logs*[1] *2 inches and wider, 16 inches and longer*
(In percent of net log scale)

Lumber grade	Dimension yields by log grades—		
	1	2	3
FAS	25.5	5.8	0.7
Select	6.9	3.6	.4
No. 1 Common	18..1	21.3	10.7
No. 2 Common	5.9	11.0	12.7
Subtotal	56.4	41.7	24.5
No. 3A Common[2]	2.1	3.7	4.9
Total	58.5	45.4	29.4

[1] Derived from yields in tables 1 and 3. For example, yield of FAS lumber (0.353) in grade-1 logs is multiplied by yield of dimension (0.772) in FAS lumber. Converted to percent, the product is 25.5.

[2] Dimension stock is not ordinarily made from No. 3A Common lumber.

Sawmill-Rough Mill Process Yields

Some dimension manufacturers are successfully producing dimension stock directly from logs. Other lumber producers are considering the addition of rough mills and dry kilns next to their sawmills.

For these processors, estimating dimension yields for a specific cutting bill from graded logs is now feasible. Table 5 indicates predicted dimension yields from graded Appalachian red oak (group) logs. Some yield applications are listed previously. Thus processors have production alternatives that can

be tailored to their end-product requirements.

Dimension Directly from Short Roundwood

Ideally, lumber sizes should be tailored to the needs of the rough mill. The control of lumber lengths begins in the woods when trees are bucked into logs. Some processors and researchers recommend the manufacture of short logs or bolts directly into dimension. In one case, it was found that logs from lower-grade hard maple trees were 25 to 45 percent more valuable when processed directly from bolts into dimension stock rather than from logs into graded lumber and then into dimension stock *(Hamilton 1970)*.

Other research work concerns processing woods and logging residues of high-value species into dimension. In West Virginia, sprout black cherry trees that would not have been logged led Koch et al. *(1968)* to remark that the direct processing method "offers considerable possibilities." Likewise, the North Central Forest Experiment Station found that black walnut logging residue in southern Illinois contained "a wealth of dimension stock." Yield work continues there on immature cherry trees and logging residue. Short-log processing research is also under way at the Northeastern Forest Experiment Station's Forest Products Marketing Laboratory at Princeton, West Virginia.

These processing methods are receiving considerable attention by research. More information will be available in the next few years.

ACCURACY

Throughout this paper, the word "predicted" precedes the yield percentages. Since they are based on sample data, the percentages are not always accurate during a short-term production run. Over the long term, they will give good estimates.

Specialists who apply lumber-yield information are emphatic when they say, "The hardwood log grades . . . have proved accurate time and again for estimating lumber quality" *(Martens 1965)*. Or "Thus far, the yields have always worked out reasonably well, especially for such small samples" *(Screpetis and Carpenter 1970)*. Furthermore, the Northern Hardwood and Pine Manufacturers Association adopted log-grading rules that are based on Forest Service hardwood log grades *(Stump 1970)*.

Predicting dimension yields, on the other hand, is more refined than predicting lumber yields. In-plant experience has shown the charts to be accurate within 3 to 5 percent *(Dunmire and Englerth 1970; Schumann and Huber 1969)*. Because the charts published in *FPL 118* are based on a representative sample of kiln-dried 4/4-inch hard maple lumber, correction factors are used to change the optimum yields to practical yields for industrial practice. For example, yields of clear-2-side dimension stock are about 2 percent less than yields of clear-1-side dimension stock. Although not in-plant tested, percent reductions may be made to total yields for dimension stock with thicknesses greater than 4/4-inches:

Grade	*Lumber thickness, in inches* 5/4	6/4	8/4
FAS	2	3	4
Select	3	4	5
No. 1 Common	3	4	5
No. 2 Common	4	5	6

Little information is available about yield differences between species. Generally the charts may be used for lumber inspected according to the standard rules of the National Hardwood Lumber Association. For No. 2 Common lumber, use the charts only for species that require clear-face cuttings to make grade rather than sound cuttings. Specifically, no percentage reductions are made by some dimension firms for soft maple and red and white oak lumber. Reductions are being made for the following species: white ash, cherry, and hard maple—3 percent; and birth and pecan—5 percent. The use of the charts is precluded in warp-prone species such as cottonwood and aspen, as well as stained lumber, mismanufactured lumber and dimension, and dimension whose color is important.

We have a lot to learn about predicting dimension yields. But we have the base, *FPL-118*, from which to work. To help verify correction factors, we volunteer to act as a clearing house for yield data from industry.

PROCESS PLANNING

Controlling the flow of raw material through processes depends on the knowledge of raw-material quality. Some companies are planning and controlling this flow. Perhaps now is the time for other companies to practice quality and production control by aiming toward the objectives of progressive process planning. These objectives are: (1) conserve the raw material, (2) engineer the process, (3) meet the specifications of the product, and (4) reduce production costs.

Specialists are available to help meet these objectives. Consultants, as well as State and Federal utilization specialists, are ready to help processors adopt research results. Together they can define more precisely the quality of the raw material that will encourage the growth and development of the forestry-based enterprises.

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MANUFACTURE OF OAK FURNITURE, CABINETS, AND PANELS

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ABSTRACT. Oak is uniquely favored for use in furniture, cabinets, and similar products. The supply is plentiful. Though drying presents some problems, once oak is properly dried it is a stable wood that machines very well, glues well, and accepts a variety of finishes well.

FROM THE VIEWPOINT of a woodworker, I shall discuss chiefly those technical considerations that are of concern in the conversion of rough oak lumber into consumer products such as furniture, kitchen cabinets, and similar household and institutional fixtures. I shall make no distinction between the red oaks and the white oaks. There are differences, of course; but from the woodworker's viewpoint, these differences are minor.

You already have general knowledge about the characteristics of wood as a raw material for all types of manufactured products. You are aware of its anisotropic structure, which causes it to exhibit differing properties in its mutually perpendicular axes of symmetry—radial, tangential, and longitudinal. You know that wood is hygroscopic and undergoes dimensional change in changing atmospheres, particularly with protracted changes in humidity. Wood is variable in its anatomical structure, which gives rise to varying characteristics of strength, machinability, workability, appearance, and adaptability to finishing.

In its typical combination of all these variables, oak stands prominently unique among the furniture woods. In some respects it is most highly favored. In other ways, it presents challenging problems.

One respect in which oak holds an unchallenged position among furniture woods is its availability. This is not only because of its broad distribution and abundant proportion in eastern forests, but also because it can be harvested feasibly. A high level of demand for pallets and for oak flooring in homes, highway trailers, and railroad cars has provided a market for the lower grades of lumber. Consequently, substantial quantities of No. One Common and Better grades of lumber become available at reasonable cost for conversion to manufactured products requiring the higher grades. Most other species are not so favorably available from the wood processor's point of view.

Another advantage of oak is the typically larger size of logs that come to the sawmill. Not only is mill cost minimized, but also the average width of board is thereby increased. Net yield in the rough mill or the

cut-up plant is improved in turn by a reduction in the proportion of edging waste.

THE DRYING PROBLEM

It is in the drying of the rough green lumber that the principal problems arise in the utilization of oak for furniture; and as a generality it can be said that the key to really successful use of oak for furniture and cabinets lies in the seasoning of the lumber. Oak is not difficult to season properly if procedures are followed that the nature of the wood calls for.

Oak has a tendency to develop surface checks on flat-sawed faces during drying. This tendency is the result of two principal features. First, oak shrinks a considerable amount during drying. Shrinkage of width in a flat-sawed board in drying from green to 6 percent moisture content can be as much as 9 percent. This is in the direction parallel to the annual growth rings. Across the rings, or radially, shrinkage is about one-half this amount. The presence of the many large rays alined perpendicular to the rings restrains shrinkage in edge-grain boards. In flat-grain lumber, on the other hand, the rays form points of weakness, which tend to rupture and create surface checks as the surfaces of the boards begin to dry and try to shrink around the still wet and swollen core of the board.

These tendencies exist in all species of lumber. They become of particular importance in oak because of oak's characteristically large overall shrinkage and because the rays are large and numerous.

Although it is difficult to completely prevent surface-checking in drying oak, precautionary procedures can avoid damaging the lumber for furniture use. The principal requirement is to restrain the rate of drying so that excessive differences in moisture content do not develop between the faces of the boards and the interior portion or core of the board. This can be most effectively done by entering lumber directly into dry kilns, green from the saw. Here the temperature and humidity can be closely controlled and the drying rate can be regulated.

Drying green from the saw, however, is time-consuming and perhaps wasteful of kiln capacity. Frequently kilns are not immediately available. The common practice is to allow lumber to air-dry and lose most of its free water before kiln-drying. The precaution necessary is to avoid as far as possible exposure to rapid air movement across the piles during times of high temperature and low humidity.

A procedure has been advocated, and experimentally substantiated by the USDA Forest Products Laboratory, which calls for surfacing of green lumber before drying to retard surface-checking. Presumably the procedure minimizes local stress concentration and enables the board to withstand the extreme stresses that develop in early drying stages.

Once partially air-dried lumber is entered in the kilns, it is still necessary to restrain the drying rate by use of low temperatures and high humidity. The wood of oak "softens" or becomes more "plastic" than the wood of many other species when heated. Case-hardening can develop rapidly, and there is danger of honeycombing if high temperatures are used before the center of the board is dried below the fiber-saturation point. At a moisture content of 20 percent or less, maximum temperatures can be used without damage. Careful attention to a final conditioning treatment must be given to relieve case-hardening.

With these precautions in air-drying and kiln-drying, most surface checks in oak will be completely cut away in subsequent planing and machining operations.

A STABLE WOOD

Once dried, oak is a stable wood. It stays in place well and reacts less to seasonal humidity changes than some other cabinet woods such as beech or maple. This is in spite of the fact that oak shrinks a great deal in the original drying.

With oak, as with all woods, the principal requirement for good cabinet work is that it be uniformly dried to a moisture content not in excess of 6 percent. It is the differences in moisture content of the several

component parts of an assembly that cause trouble after manufacture.

I would emphasize again that the key to successful use of oak in cabinetry is in the seasoning of the wood. Once this is properly accomplished, you are almost home free because oak is an excellent wood from the woodworker's standpoint.

Let us look briefly at the matter of yield in conversion. The oaks are graded under the standard rules of the National Hardwood Lumber Association. No special allowances or restrictions enter into the grading. Grade for grade, therefore, the net yield for any given cutting bill will be generally similar to that obtainable for any other species graded under the standard rules. Typically, however, the oak lumber that normally enters the furniture market is relatively free of surface irregularities—swirls, burls, twig knots, small mineral streaks, etc., which must be removed in clear face cuttings. This fact tends to improve the yield.

Oak does exhibit a color range, although the heartwood-sapwood contrast usually is not as strong as in such furniture species as birch and walnut. The prominence and variability of grain pattern in the oaks also introduces some complication in conversion. It is here that the skill of the woodworker enters. These features of contrast are reconciled by thoughtful planning of the cutting bill to allow the sawyer a choice in taking his cuttings from the board as it comes to him on the table. One objective must be to provide cuttings at the saws, such as interior or less-exposed parts, which will admit off-color material or flashy grain. If attention is then given to color and grain pattern in matching strips for panels or in laying up for the molders, it is not difficult to fabricate parts to quality specifications with a high level of yield.

WORKING PROPERTIES

In working properties, few species outrank oak as an all-around material. In some respects, oak is exceeded by no other species.

Oak glues readily. Of all the dense hardwoods, it is perhaps the easiest to glue and is adaptable to all the conventional adhesives. Because it tends to lie flat, with a mininum of twist or warp in strips, it works well in edge-gluing machines such as high-frequency and steam-heated flat-bed presses. However, caution must be used, in hot-platen presses because there is a danger of surface-checking if moisture content exceeds 6 percent.

In machining, no serious problems are encountered. Because it is a dense wood and generally straight-grained, oak is subject to relatively little tear-out, chipped grain, fuzziness, or raised grain. It lends itself readily to sanding. In fact, because of the porous grain structure of oak, coarser grit abrasives can be used for final sanding than with close-grained diffuse-porous woods. Paper does not load up, and burning is no problem. Life of sandpaper is greatly extended.

A few years ago, the USDA Forest Products Laboratory published the results of a great deal of research on the machining properties of native hardwoods. They evaluated some 34 commonly used species for comparative behavior in planing or molding, shaping, turning, boring, mortising, sanding, nail-splitting, and screw-splitting. The top ranking wood of all these species in properties of planing (or molding), sanding, boring, and freedom from nail- and screw-splitting was red oak. In the other machining operations red oak ranked no lower than tenth. Differences between the white and red oaks were small. Endorsed by such authority, oak ranks as a superior wood for working properties. Our experience in our shop confirms this.

Aside from oak's position as an adaptable raw material for the woodworker, it is, of course, the viewpoint of the marketplace that determines the extent to which it will be accepted as a furniture wood. Here the principal considerations are design and finish. There is ample evidence that designers and finish technologists have been able to develop a happy marriage with an intrinsically fine wood.

MANUFACTURE OF INDUSTRIAL PRODUCTS FROM OAK

by HUGH W. REYNOLDS, *Engineer, Forest Products Marketing Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Princeton, W. Va.*

ABSTRACT. The three largest and fastest growing markets for oak are railroad crossties, reusable pallets, and truck and container flooring. Manufacturers of oak lumber are advised to keep these products in mind when planning their production.

INDUSTRIAL PRODUCTS are those products purchased by an industry for its own use. Industrial purchasers have definite specifications and requirements.

The "romance of wood" and its beauty are not applicable here. Competition is keen between manufacturers of wood products and with manufacturers of nonwood products.

For three industrial products, oak has an advantage over other wood and nonwood materials: railroad crossties, returnable pallets, and laminated truck flooring. In the market for each of these products, the potential for sales is large and expanding. The sizes of wood used in manufacturing each of these products are different. Crossties are made from big pieces of wood; pallets are made from smaller pieces; and flooring is laminated from very narrow pieces, some very short.

CROSSTIES

Consider the oak sawmiller who has good-size logs. Work at the Forest Products Marketing Laboratory by Garrett *(1969)* has shown that medium-quality factory-grade 2 red oak logs and poor-quality factory-grade 3 red oak logs can be more profitably sawed into ties, timbers, and lumber than into lumber alone. The reasons for this are that sawing time per log is decreased, while the total volume recovered from the log is increased.

Log lengths and railroad crossties are not always compatible, and the wastage that occurs was taken into consideration in the study. Church *(1969)* has shown that the necessary grading and scaling needed to determine the type of log most profitably utilized for this purpose is easy and inexpensive.

Fifty to 55 percent of all ties used are made of oak. The plentiful supply of oak is one reason, but the desirable characteristics are more important. Toughness, durability, and strength are necessary for ties. Formerly the more decay-resistant white oak heartwood tie was preferred to the permeable red oak tie. Now all ties are preservative-treated, and the more permeable red oak is preferred.

In the past, railroads have delayed replacing old ties. Now the demand for ties is exceeding the supply, and prices have risen. Crosstie production rose above 1 billion

board feet—25 million ties—in 1970. Estimates for the next four decades are that this level of tie demand will hold fairly steady.

As railroads have been merging, crosstie requirements have become more stabilized; the boom-and-bust cycle is a thing of the past. The use of concrete ties—bigger ties spaced farther apart in the tract—has been disappointing. Laminated hardwood ties (3 by 8 inches, 4 by 6, 5 by 7, or 6 by 7) timbers have given the advantage of the wider spacing without the fracturing characteristic of the concrete tie. It is very nice to report that wood, especially oak, beat the competition for a change. Contracts for tie production are now common.

PALLETS

Now consider the oak sawmiller or manufacturer who has poor-quality logs. These are the logs that are too poor to yield good lumber and yet are not large enough for tie and timber production. However, these poor-quality logs are suitable for the market for returnable pallets. We at the Forest Products Marketing Laboratory have designed the SHOLO process *(Reynolds and Gatchell 1971)* to convert very low-grade hardwood logs to pallet parts and pulp chips. With slightly better logs, cants can be made and resawed into pallet parts. Some specialty sawmills purchase poor-quality sawlogs, make lumber, and immediately cut all this lumber into parts. Pallet-quality cants and pallet-quality lumber enjoy a steady though low-priced market.

Strobel and Wallin *(1969)* have completed a 4-year study of pallets in use in the food industry. Their findings show that oak pallets, assembled green, either outlast or equal the life of softwood or plywood pallets. Maintenance was no greater with oak, though initial prices per pallet were higher.

John Strobel, a cooperator in these studies, has developed a new organization to lease pallets. This one new firm alone may buy up to 100 million pallets annually when full-scale operations are funded. This could raise the demand for pallet material from 3 billion board feet per year to 5 billion board feet per year.

As the demand for pallet material increases, prices will increase, and quality specifications will demand more attention. Annual contracts for cut-to-size pallet parts will become commonplace. Centrally located pallet-assembly plants will draw parts from many sawmillers. It is estimated that prices will rise to $140/MBF for guaranteed quality parts ready for assembly.

FLOORING

But many pieces coming from oak logs are not wide enough for pallets that require a 4-inch minimum width. However, the narrower material can be used for laminated truck flooring. This market uses planed and kiln-dried lumber ripped into very narrow pieces. After the defects are cut out, the pieces are laminated on edge, the planed surfaces being glued together. Only the handling and drying costs dictate how small a piece of lumber can be used for this purpose.

In 1968 there was a demand for 36 million square feet of laminated truck flooring. One square foot of flooring required 4 board feet of lumber, so this demand translates into 144 million board feet. As the trucking industry grows and the use of containerization increases, the demand should continue to rise. Oak is the predominant species for this, and maple is a close second.

Oak is the preferred species for many wooden products produced for industrial use. Only three of these have been mentioned. Very large pieces can be used for making crossties; much smaller pieces can be used for making pallets; and narrow pieces can be used for making laminated truck and container flooring. So the oak manufacturer has a choice of products that he can produce. Which products he will produce will depend on his locality and the contracts offered for his products.

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RECONSTITUTED PRODUCTS FROM OAK

by W. C. LEWIS *and* B. G. HEEBINK, *Research General Engineers, USDA Forest Service, Forest Products Laboratory, which is maintained at Madison, Wis., in cooperation with the University of Wisconsin.*

ABSTRACT. "Reconstituted" describes a family of panel products made from fractionated oak, bonded with either a synthetic resin or a natural lignin bond. Several current commercial fiber panel products from oak are described, and the status of research on experimental products and processes is presented. Recent technological developments are removing the stigma associated with the use of oak as raw material for reconstituted panel products. It is probable that in the future reconstituted panels will be manufactured by a dry rather than a wet process.

FOR LACK of a better term, "reconstituted" is used in this paper to denote a family of panel products made from fractionated oak, bonded either with a small percentage of synthetic resin or a natural lignin bond supplemented with additives. The discussion is limited to the use of round wood. Primary emphasis is given to commercial fiberboard, hardboard, and particleboard, with a discussion of some promising experimental products and unique methods of breaking down oak round wood into prescribed particles.

Technically, a hardboard or an insulating board can be made from oak or any other lignocellulosic raw material. The term lignocellulose is used here because the woody tissue of other plants must be included. There are successful plants in other parts of the world where bagasse (sugar cane fiber), papyrus, flax straw, and cereal straw have been or are being used for fiberboard (insulating board and hardboard).

In the United States, the hardboard and insulating board industries have developed primarily around the use of low-density hardwoods and conifers. The conifers were used first in insulating board materials, and it was the consensus 25 years ago that one of the requirements for a suitable insulating board was a long-fibered softwood. Research and experience have shown that, with the proper equipment and conditions for fiber manufacture, the shorter fibered hardwoods can be used to make insulating boards with quality comparable to those made from softwoods.

Hardboards with some more desirable properties, such as surface finish, can be made more easily from hardwoods than from softwoods. This preference for low-density hardwoods over the more dense

ones in the United States is based on practical and economic reasons. In other areas of the world, where low-density species are not available in the quantity needed, high-density species like beech are used successfully.

COMMERCIAL FIBER PANEL PRODUCTS FROM OAK

Oak has been and is being used in the United States for both insulating and hardboard manufacturing. Examples include the following:

- Temple Industries, at Diboll, Tex., blend a substantial amount of oak into the furnish for their insulating board products. This plant, one of the newer ones in the United States, has been successful, and is expanding production.
- The U.S. Plywood-Champion Papers Corp. plant at Catawba, S. C., was based on the use of oak as the major raw material. They make a fully competitive line of medium-density and high-density hardboard products. Some products are made exclusively from oak; for other products oak is used in blends with other available species.
- Societa Italiano Rueping, of Naples, Italy, who use oak slabs for hardboard, are cited because of the problem they have had with acceptance of their product in competition with the lighter colored board prevalent in Europe. Not only was the darker color objectionable, but uniform color was more difficult to maintain because of the extractives in oak.
- Alton Box Co., of Alton, Ill., use substantial portions of oak in their furnish for corrugating medium and linerboard. This use is cited because the method of pulping and the fiber requirements are similar to those needed for insulating board or hardboard.

INDICATORS OF USING OAK FOR FIBERBOARD

It has been said that the main reason for using low-density hardwood or softwood has been economic rather than technical. To support this statement it is desirable to cite literature that indicates the technically oriented possibilities for using oak or similar dense hardwoods.

S. L. Schwartz *(1943)* described research in which he used white oak from eastern Virginia. He described how the pulp was produced, using Defibrator equipment, how more alum or other fixing agent was required to set the size because of the tannins present, and how (when hot water removal of tannins was used) board size could be fixed with one-third the chemical, though lower strengths resulted.

Schwartz and Baird *(1952)* demonstrated that both insulating board and hardboard of reasonable quality could be made from sand hickory.

S. Hunter Brooks, Rust Engineering Co., in a paper presented at the Mid-South Section Meeting of the Forest Products Research Society in October 1970, showed some interesting possibilities for oak and oak bark. His hardboard was based on the Miller-Hofft system of producing fiber by a pressurized refiner, and curing a fiber-based board with about 8 percent urea-formaldehyde binder with high-frequency heat. Here the properties were comparable to or exceeded commercial standards for medium-density hardboard or particleboard when the board was made from either kiln-dried oak hogged fuel or green oak pulp chips. Brooks stated also that a board made from 100-percent oak bark had fair physical properties, enough so it passed minimum values for floor underlayment.

DRAWBACKS TO OAK FOR BUILDING MATERIAL

So far all indications are that more oak could be used for building fiberboard products than is being used. Why then has not the practice developed more than it has? Some of the reasons are:

1. The consumer associates quality with color, particularly in insulating board, and he wants a light color. But an oak-based board is usually dark-colored. In hardboard this darkness is grayish or black as compared to tan or brown for boards from other species.

2. Plants are designed and built based on past experience. For most insulating board and some hardboard the groundwood process is used, but it does not produce as good fiber from a dense hardwood as a lower density one. The other predominant method for fiber preparation has been the Asplund defibrator. It too does not produce as good a fiber from dense woods unless a semichemical treatment is used. A newer development for fiber manufacture, that of producing fiber by refiner methods under pressure (pressure-refiner) sometimes referred to as chip groundwood, offers distinct promise of producing better fiber more economically.
3. All insulating board and much of the hardboard is produced by the wet process. The extractives present in oak and the sugars produced from more severe steaming, cooking, or temperatures used during refining require more water for washing (and thus more water pollution) than when conditions are milder with a lower density species. Even when a dry process is used, the presence of these soluble materials with their variability affects uniformity in manufacture.
4. Oak as a species is plentiful, but much of it is of the "scrub" variety. It is small in diameter, irregular in shape, and apt to have a high frequency of knots. Yields and conversion are poor because of the form and shape.

If comparative costs of other raw materials change enough, and oak becomes more economical, then more oak will be used for board products. This relative balance of cost continues to shift. Many raw materials being used today were impractical and uneconomical yesterday.

EXPERIMENTAL PRODUCTS AND PROCESSES

Use of Oak in Particleboard

Ever since the beginning of the particleboard industry in this country, about 20 years ago, a stigma seems to have been attached to the use of oak. Many researchers have found that, in general, the best particleboard can be made from the low-density woods. Thus the domestic oaks, hickories, and some maples are certainly not on the preferred list. When a comparison is made with flake-type boards, using bending strength as the criterion, a plot of strength versus density of raw material is an ascending line with decreasing species density. In spite of this, there is limited use of mixed hardwoods, including oak, in the cores of commercial three-layer particleboards, probably for economic or availability factors, but sometimes because of a basic difficulty with some competing species.

A far more intriguing potential for using dense woods in particleboard, again illustrating the extreme flexibility of the process, is the current trend toward smaller fiber-like particles, such as those produced by attrition milling. Commercial boards of this type, primarily from softwoods or low-density hardwoods, have been on the market for some time and have been variously called particleboards or dry-formed hardboards. More recently, experimental boards of this type were made from dense hardwoods by similar processes, and they appear to be entirely satisfactory for furniture core stock. The edges of these boards are tight (often a problem when working with oak) and the density and resin content are normal for core stock. If subsequent pilot-plant evaluations substantiate the findings of exploratory work, particleboards of this type could develop a sizable market for oak round wood.

Exploratory work at the Forest Products Laboratory has developed some promising properties in particleboards made from fine splinters, as well as bundles of fibers, torn out of Douglas-fir by what might be described as a modified groundwood process. Progress in this direction is temporarily halted because of equipment difficulties; therefore, no evaluation of oak by this process has been made. If future tests on oak yield particle geometries similar to those already produced from Douglas-fir, the properties of the oak boards should be similar to those of the Douglas-fir boards already tested. Thus the process could offer

a means of producing fiberlike particles directly from round wood without depending upon knife cutting.

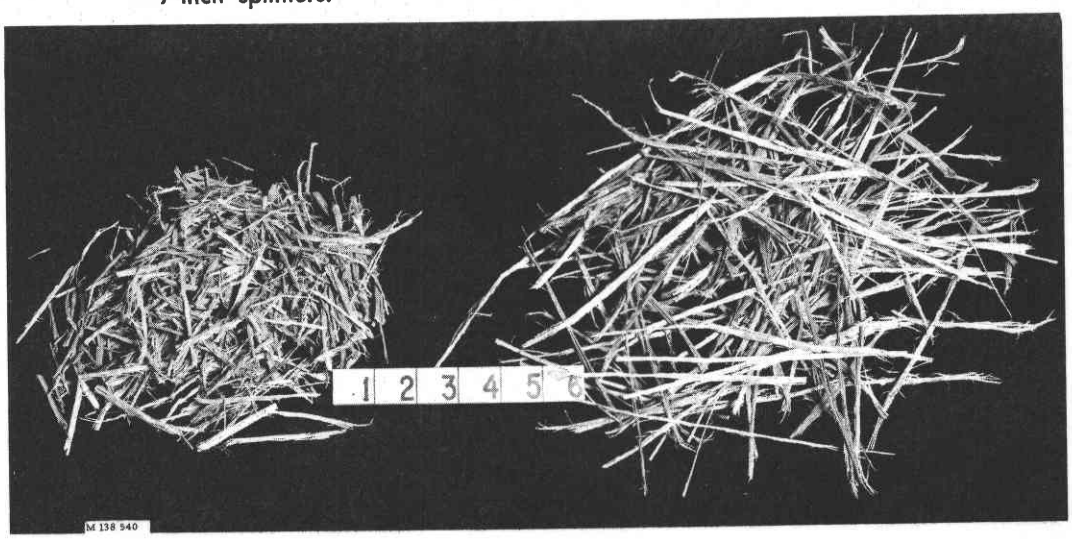
Oak Splinters Developed by TVA

The Timber Harvesting and Processing Section of the Tennessee Valley Authority, Norris, Tenn., is exploring several approaches to the problem of better utilization of low-quality oak logs. One of these studies is concerned with breaking down oak logs into coarse, rather long particles that perhaps can best be described as "splinters." These splinters are produced on equipment designed and built in their own facilities to demonstrate the principle; later this may provide design information for prototype equipment. It is TVA's hope that private industry, through a licensing procedure, will develop a prototype machine and possibly production equipment.

Their present equipment involves a set of heavy rolls to break down the wood. Surfaces of the rolls are machined in a special pattern to promote crushing, separating, and spreading of the fractured oak. After several passes through these rolls, an oak log is reduced to a mat of loosely attached splinters. This mat is then cut into shorter lengths, which are in turn fed through a machine called a "scrubber." In the scrubber the reciprocating action of two inclined serrated plates separates the splinters and further reduces them in size.

Having demonstrated that splinters of this type could be made, TVA approached the Forest Products Laboratory for suggestions on the possible uses for particles of this type. A conference on the possible uses was held, with particular reference to the capability of the process to produce splinters of specified sizes. It appeared that smaller splinters for use in pulping would probably be impractical; therefore, products made from coarser splinters were surveyed. Two approaches were considered: (1) using splinters about 3 inches long (left in figure 1) in a phenolic-bonded particleboard designed for house-wall sheathing; and (2) using splinters about 7 inches long (right in figure 1) in a cement-bonded board or as the core of a cement-bonded board having conventional excelsior faces. Both approaches yielded test results that look exceedingly encouraging, and the work is being continued with emphasis on promising variations.

Figure 1.—Oak "splinters" produced by TVA: left—3-inch splinters; right —7-inch splinters.



CONCLUSIONS

Recent technological developments, improved fiberizing techniques, and current research on fiber and particleboard processing are rapidly removing the stigma so long associated with the use of the oaks and other dense hardwoods as raw material for reconstituted panel products. The future expansion of the market for oak round wood in reconstituted form, therefore, will be determined by economic considerations, availability, and increasing scarcity of low-density species rather than a lack of technical knowledge. With increasing concern over controlling and reducing water pollution, it is probable that in the future reconstituted panels from oak will be those designated by the terms dry-formed hardboard or particleboard.

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UTILIZATION OF OAK RESIDUES

by RICHARD C. ALLISON, *Forest Products Specialist, Cooperative Extension Service, The Pennsylvania State University, University Park, Pa.*

ABSTRACT. Residues should be thought of as a raw material for specific uses rather than as a waste. Fines and solid wood residues are usually kept separated in waste-collection system, but species are rarely kept separated. The properties of each species dictate what uses can be made of them. Quantity, location, cost, moisture content, physical size, and presence of foreign matter should be known if the raw material is to be marketed for a specific use. Each kind of residue has certain potentials for use. Case examples cited indicate how firms are marketing their residues.

SLABS, EDGINGS, end trim, sawdust, planer shavings, and bark generated by the forest-products industry can be referred to either as *residue* or *waste*.

If residues are considered as being a waste —useless, and having no value—then they will be treated as such, to be disposed of as quickly and inexpensively as possible. The right way to treat residues is to consider them as byproducts to be used for some purpose. This is the key to the utilization of residues.

KINDS OF RESIDUES

In making lumber, less than half of the original log is converted into the primary product at the sawmill. The rest of the log becomes residue in the form of slabs, edgings, end trim, sawdust, and bark. Residues from secondary remanufacturing include solid wood residue, sawdust, sander dust, and shavings.

Residues generated by these industries can be put into two classes. First is solid wood residues, which include slabs, edgings, end trim, and lumber scraps that are not designated for paper chips. The second class includes the fine wood residues—sawdust, sander dust, and shavings. Bark will be treated separately.

PROBLEMS WITH UTILIZING

One difficulty in the use of oak residues is that they are rarely kept separate from the residues of other hardwood species being manufactured. Sawmills and wood-manufacturing firms normally process species separately, but their residue-collection systems are not designed to keep the residues segregated by species. However, there are firms that specialize in processing and manufacturing oak products exclusively, or a major portion of whose production is in the oaks species group. This facilitates marketing the oak residues as a single species group. Unless a specific market is developed that would pay a premium price to warrant separating oak from other hardwood residues, I doubt

that operators would take the time and trouble to do this.

Certain problems are inherent in utilizing and marketing wood residues. These range from the properties of the species themselves to the general economic situation. For example, certain properties of the oaks—such as high tannic acid content, dark color, and disagreeable odor when wet—make them unsuitable for commercial uses like wood flour.

Condition of Raw Material

The condition of the residue material will dictate whether it can be used in its present form or will have to be altered in some way to make it marketable. Consider:

Quantity.—What volume is available on a continuous basis? Will it be too much or too little to supply a market outlet? If too little, can other sources of similar material be obtained?

Location.—Where is the source of the material in relation to the market outlet? Very often the supply is too distant from the market outlet. Transportation cost often exceeds the value of the market price for the material.

Cost.—Is a value assigned to the residue itself? If so, is it a minus, zero, or plus value? If a plus value, will it be too high with the added costs of processing (if necessary), handling, and transporting to a market outlet to make it noncompetitive or unmarketable?

Moisture content.—Is the material green or dry? If green, will it have to be dried to sell? Can the drying costs be recovered in the selling price, or will the added cost of drying make the finished product noncompetitive or unmarketable?

Particle size.—Size of particles has a bearing on the uses that can be made of residues. For example, sander dust cannot be used in foundry molds: it is too fine. It may have a use as wood flour, extender, or filler in adhesives and plastics, or as an additive in a molded product. The fine sawdust particles from a bandsaw can be used by the carbon industry, but sawdust from circular saws is too coarse. Coarse and fine sawdust particles are being experimented with as a roughage in feed mixes for cattle. Perhaps one size of particle will be preferable over the other. Solid wood scraps may have to be hammermilled, hogged, or ground to a certain size to be marketed. The cost of processing has to be recovered in the sale price.

Foreign material.—Soil, grit, and stones are present in bark residue. This foreign matter makes the residue unsuitable for use as a boiler fuel because of excessive clinkering and glazing of fire grates. Ponding or washing logs would reduce this problem. There probably is a technique for removing this material from the bark residue, but the expense may be too high to make it practical.

Species.—Certain species are in higher demand than others. A combination of birch, beech, and maple have ready markets for some purposes.

Other Considerations

Once the raw-material conditions are known and evaluated in relation to the market outlet, then a reasonable estimate can be made to determine the profitability of processing the material and transporting it to market.

Several intrinsic factors make utilizing residues difficult. One is the relatively low value associated with the products. Because most residues do not command a high price in the market place, they cannot be transported too great a distance. Animal bedding, for instance, is normally marketed within a 50-mile radius of the supply. On the other hand, attractively packaged bark mulch nuggets are shipped nationwide by rail for distribution to retail market outlets.

A considerable investment may be required to handle, process, bale, package, transport, and market residues. This can be undertaken by the firm that generates the residue, or by an idependent firm specializing in processing and marketing residues. Assistance from brokers, wholesalers, and consultants may be necessary.

Sawmills and secondary remanufacturing firms should have certain basic equipment for handling and storing residues for marketing. They would need a bucket loader, an elevated storage bin, an open or closed pole-type storage shed, large tandem dump-

or flat-bed trucks, and possibly mechanical conveyors and blowers. Waste-collection systems may have to be altered to make residues available for market. Unless a reliable market for the residues is assured, these firms are reluctant to discontinue their present methods of disposal by burning and dumping and to invest in additional equipment for processing and handling residues.

CASE EXAMPLES

Perhaps more than anything else the aggressiveness and ingenuity of the individual faced with a residue-disposal problem are the key marketing factors. Other less aggressive firms may be forced into action because of the enactment and enforcement of state laws against dumping and burning. Several firms have faced this problem and have taken the necessary steps to market their residues. Others have been farsighted enough or have seen the profit potiential for marketing their residues and are doing this. Several case examples are outlined below to give an idea of how some mills are marketing their residues.

Pallet Manufacturing Firm

This plant generates about 30 tons of green hard maple and beech lumber scraps and 75 tons of green sawdust and shavings per week. Their former method of disposal was to convey and blow all their waste into a wigwam burner.

Their first step was to erect a bin for the sawdust and shavings to be sold to local dairy farmers as bedding. But experience indicated that only a small percentage of the material could be used in this way, and the rest had to be burned. In addition, slow demand for the bedding material during the off season made the bin useless for extended periods of time. Enforcement of the air-pollution laws against burning has caused this firm to increase its efforts to market their residues.

The next step they took was to purchase a 5-ton stake body dump truck and equip it with a blower to deliver sawdust and shavings to local dairy farmers for bedding (fig. 1). Economical trucking distance for this size truck is about 25 to 50 miles. They are thinking about purchasing a 20-ton truck and equipping it in the same manner

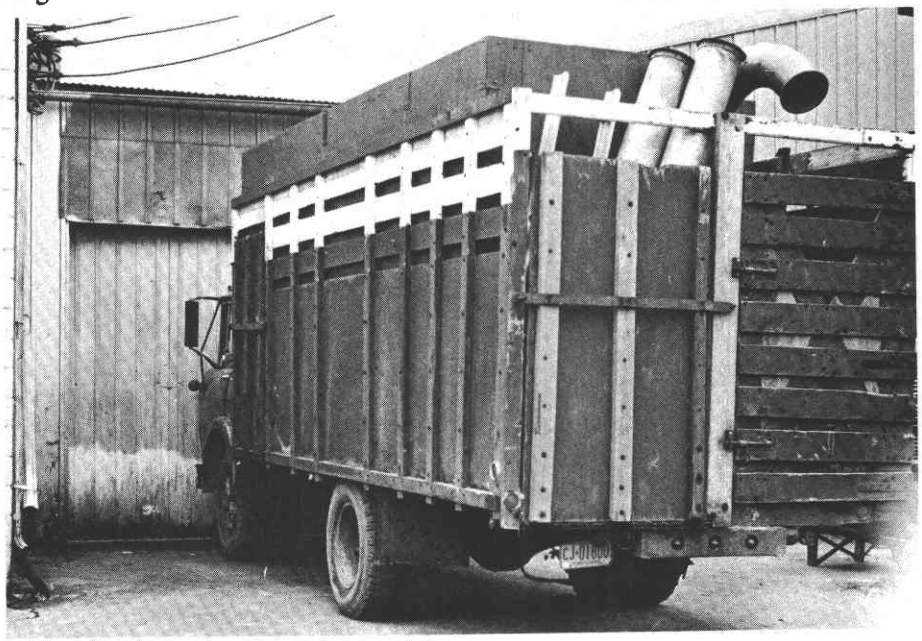


Figure 1.—A 5-ton stake-body truck equipped with motor and blower for delivering sawdust and shavings to local dairy farmers.

to extend their marketing radius to 100 to 150 miles.

They have worked closely with the county agent to advise local dairy farmers about the availability of the residues for bedding. They also have exhibited at an agricultural field day and have advertised in farm journals and local newspapers. Income from the sales is paying for the initial investment and allows a small margin of profit.

Competition from local sawmills has made it difficult to enlarge this market. The firm has had little success with other means of utilizing the residues, such as baling or packaging them for retail sales as a mulch, or the manufacture of pulp chips. They are searching for a suitable dumping site for their sawdust and shaving accumulations where these residues may be reclaimed for future use.

Medium-Size Sawmill

This sawmill generates about 30 tons of green oak bark and 40 tons of green mixed hardwood sawdust per week. In past years all bark was dumped at the mill site and the sawdust was stockpiled in an open pole-shed storage building. The sawdust was marketed to local dairy farmers for bedding.

Markets for these residues has completely altered this past year. All sawdust is being trucked by van to the Buffalo area for the carbon industry. In addition, this mill is buying sawdust form several other local sawmills for this market. The supplying mills have erected bins to facilitate loading the van (fig. 2).

Bark is now being shredded and blown into on open pole-shed storage building (fig. 3). It is loaded by a bucket loader and is trucked to local dairy farmers for bedding. Use of bark as a bedding material is being cautiously accepted by the farmers. Their main complaint is the dark color, which makes the bedding area look dirty and unattractive.

Several other markets for the shredded bark are being investigated. A large local nursery will be using the material this spring after it has aged for several months.



Figure 2.—A large steel tank used as a sawdust bin to load an open trailer van. Sawdust is trucked to Buffalo for the metallurgical industry.

It is being considered as a mulch for strip-mine reclamation projects and as an industrial boiler fuel. The sawmill owner has experimented in baling bark with a conventional hay baler, but had little success. The material would not compact so it could be held together with baler twine.

Bark Mulch Processing Plant

A centralized bark-processing plant was established last year to manufacture shredded hardwood bark mulch for the home consumer market. It was designed and located to procure bark from three to four local sawmills. The predominant species being used are oak, cherry, and hard maple.

The raw bark is trucked by the mills to the processing plant in tandem dump-trailer loads. This bark is then stockpiled for a period of several months to allow it to age before processing. One of the principal

suppliers is reclaiming bark from a dump pile; the other purchased a tandem dump trailer and is diverting his bark from a burner waste conveyor to the truck. This is a good example of how burning may be eliminated and the material may be utilized for a useful mulch product.

The aged bark is processed through a hammermill, after which the fines are screened out by passing the shredded bark over a ⅜-inch vibrating screen. The screened material is then conveyed to a bagging hopper by a 45° idler belt conveyor. The open-mouth bags are filled by an inclined screw conveyor, using a preset limit switch (fig. 4). The 3-cubic-foot bags are then heat-sealed, flattened, and transferred to pallets.

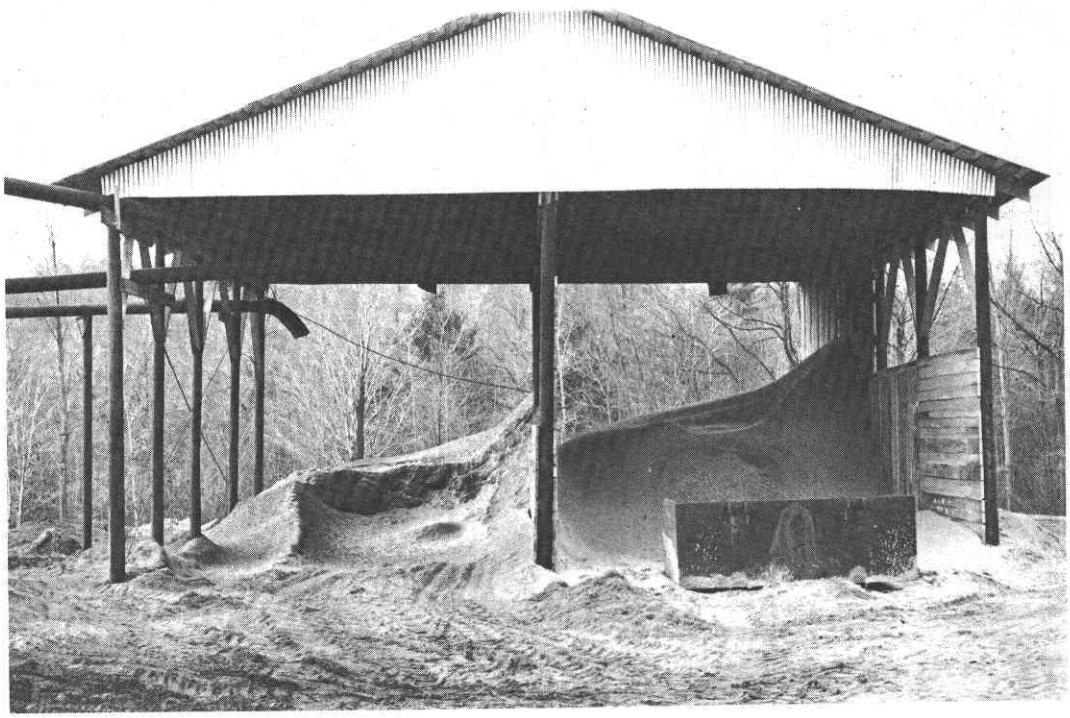
Most of the bagged material is shipped in 800-bag trailer loads to distributors or directly to retail garden-supply outlets. Shipping distances vary from 50 to 250 miles. Smaller quantities are delivered locally within a 50-mile radius. Buyers may pick up their orders at the plant, using their own trucks. Approximately 50,000 3-cubic-foot bags were sold during the first year of operation.

This kind of processing plant helps to alleviate the bark-residue problem the mills face, and at the same time affords an opportunity for a new business to be established. Several of these centralized bark-processing plants could be established in Pennsylvania to help reduce the bark-disposal problem. Some words of caution. The mulch product business is very competitive. The management of a bark-processing plant should have the background and knowledge of the nursery industry to successfully market the product.

SUGGESTIONS

What is the best procedure for marketing sawmill residues? Look at it from the viewpoint of a sawmill operator who is

Figure 3.—Open pole-shed storage building for bark and sawdust. Bark is shredded and blown into compartment on left. Sawdust is blown into compartment on right. Material is loaded into open trailer van with 2½-cubic-yard rubber-tired bucket loader.



generating bark, sawdust, slabs, edgings, or end trim. Suppose he cannot dump or burn at the mill site and must market (or dispose of) the residues elsewhere. What are the alternatives? Some suggestions are offered below.

Economics

There are outlets for residues, but they must be explored. True, using the outlets may not bring in a profit, but at least the residues will be moved. The operator should know what it is costing him to dispose of the material. This cost can be equated as a negative value because there is no return for disposal.

If enough income can be realized from the sale of the residues to bring the negative cost to zero, the owner still would be reducing his costs. An additional cost may be incurred in marketing the residues, and the operator should get a return from the sales to warrant the extra expense. Of course the best situation would be where the owner realizes a profit from the sales of his residue. In many cases this is not possible.

Some day there may be a choice between either marketing the residues or going out of business. In the future this situation will become more prevalent as enforcement of the air-pollution and solid-waste disposal laws become a reality.

Sawdust

The best market outlet for sawdust is animal bedding. Several approaches may be taken to market this material. One is to work with the local county agent to locate dairy farmers within a reasonable trucking distance. Personal contact, a sales or personal letter, or advertising in local newspapers are methods that may be used to advertise sawdust for sale. More extensive marketing areas may be covered by advertising in farm trade journals and other publications. Newsletters, prepared and mailed by extension service personnel, are another means of advertising the product. A sign erected at the mill to advertise sawdust for sale or free is another means of attracting customers.

Other possible uses for sawdust are poultry litter, mulch, soil conditioner, metallurgical uses, foundary uses, wood flour, particleboard, and industrial fuel. Each use must be investigated in detail to determine if a possible market exists and if it could be exploited economically. Advertising methods and sales contacts should be handled in a manner similar to those mentioned for cattle bedding.



Figure 4.—Filling 3-cubic-foot open-mouth plastic bags with shredded hardwood bark mulch. Preset push-button limit switch is to the immediate left of the drop chute.

Examples of local uses for sawdust include insulating natural gas lines during construction and protective covering on salt and cinder piles to prevent caking. A sawmill operator was able to convince several farmers to erect their own bins at his mill and be responsible for keeping them cleaned out. The latest use for sawdust being investigated is as a roughage in cattle feed. This use has not yet been proved satisfactory. Even if there is a demand for sawdust as a feed mix, the supplying mills would have to be in close proximity to a feed mix mill. This use does not offer much hope for Pennsylvania sawmills.

Slabs, Edgings, and End Trim

Marketing slabs, edgings, and end trim poses a different set of problems. Here we are dealing with solid wood residue. The best possible market outlets for this material in its present form are for firewood and charcoal. Selling solid wood residue for charcoaling has its limitations because of the location of the charcoal plants. Maximum trucking distance for this outlet would be about 150 miles. At this distance it would be only a break-even proposition.

Selling solid wood residue to the vacationist and home owner for firewood is probably the best alternative. Preparing the material for sale would help to market it. This could be done by cutting it into fireplace length and either boxing, packaging, or strapping it into bundles suitable for handling. The firewood could be ranked into salable units or piled loose. It could be sold at the mill site by the package or bundle, or by the trunk or truck load. It could be delivered by the mill or marketed by an independent dealer. Advertising at the mill or in the local newspapers would be helpful in marketing the material.

Bark

Selling bark is a new experience for most mills. In the past 5 years hardwood bark has become known and accepted as a mulching and bedding material. Mills should stockpile their bark where it can be easily reclaimed. They should keep their piles free of debris. I know of one case where a large stockpile of bark could not be used for processing into a shredded mulch because it was one big junk pile for everything discarded by the mill.

Wide-scale marketing of raw bark is not possible without further processing and packaging. Some mills sell small quantities to local nurseries, homeowners, and farmers for mulch and bedding. The minimum processing for retail sale would be to age the material for several months, screening out the larger pieces and packaging in 3-cubic-foot bags for ease in handling. Hammermilling should be done to get a uniform particle size or shred.

Specialized merchandising techniques have to be employed to market large quantities of bark mulch. This may be accomplished by the bark mulch processor, a broker or distributor of nursery materials, or a salesman hired specifically for this job. Very rarely does the sawmill owner have the time, interest, or know-how to market his entire bark product.

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NONINFECTIOUS DISEASES OF OAKS

by DAVID R. HOUSTON, *Research Plant Pathologist, Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, Conn.*

ABSTRACT. Noninfectious diseases arise primarily from the harmful effects of wound agents, chemical, and adverse environmental factors. Wounds directly result in damage to trees, but they are important primarily as infection courts for pathogenic organisms. Adverse environmental factors affect trees both directly and indirectly. Trees weakened by environmental stresses become susceptible to insects and fungi that normally are unable to attack. These "declines" of oak have occurred frequently in the Northeast and Southeast and will probably increase as concern for environmental quality restricts the use of pesticides.

NONINFECTIOUS DISEASES include all deleterious alterations in form or function that occur in the absence of pathogenic organisms. Wounds resulting from mechanical injuries and fire; damage caused by chemicals, including herbicides and air pollutants; and the effects of irradiation, mineral deficiencies, and adverse environmental factors, including insect defoliation, are the primary types of noninfectious diseases.

Most mechanical injuries are significant mainly as infection courts for organisms that incite discoloration, decay, cankers, or vascular wilts. For this reason, the subject of wounds is treated lightly in this paper except to note difference in susceptibility of major species to wound agents or ecological factors related to wound development.

Adverse environmental factors—particularly drought and frost—are probably the most important causes of noninfectious diseases. Oak declines, which are usually complexes of adverse environmental factors and organisms of secondary action, are treated in this paper even though infectious organisms are involved. The great importance of oak declines warrants discussion of these complexes at this symposium if for no other reason than to point out the need for further research.

Fire is a major source of injury to oaks in the Southern Appalachian and Southern States. Much attention has been paid to the discoloration and decay following wounding by fires, and several comprehensive accounts of the damage that can result have been published *(Hepting 1935, and 1941)*. The processes that result in discoloration and decay are treated in another paper in this symposium. Therefore my primary aim is to point to factors relating to severity of injury.

In general, the white oak group suffers less damage by fire than the red oaks (table 1). This is partly because the bark of the

white oaks is usually thicker, more fibrous, and lighter in color. The ability of bur oak to survive in its Midwestern habitat where fires were common is attributed to its insulating bark, which can reach thicknesses up to 4 inches in old trees.

Chestnut oak occupies sites unsuitable for other species—a factor that contributes directly to the great damage it receives from fire. On steep dry slopes and ridges much litter accumulates—and severe scarring of the upper sides of the trees results from fire. Of the red oaks, scarlet oak suffers the greatest damage from fire. It has thin hard bark, and it often grows on dry sites. By contrast, willow oaks—with probably the most fire-susceptible bark—suffer little from fire because they grow mainly in river valleys and other moist situations that are low in fire hazard.

Chemicals, including air pollutants, are agents that can cause injury to oaks. Iron chlorosis is a common problem on pin oak, from New Jersey to Michigan to Texas, and is especially prevalent on the calcareous soils of the Midwest. This problem of iron deficiency has been corrected by acidifying the soil with H_2SO_4 or by adding iron chelate to the soil, and by spraying foliage with ferric phosphate or $FeSO_4$ *(Pirone 1941, Hacskaylo and Struthers 1959, Carpenter 1951)*. By contrast, bur oak does well on the calcareous ridges of the midwest.

White oak is resistant to salt spray and to brief salt water flooding, and live oak, which occupies primarily a coastal strip from North Carolina to Texas, is remarkably resistant to sea salt salinity and salt spray. Such information could be of value in selecting species to plant along roadways in areas where salt is used to reduce winter road hazard or in areas exposed to coastal storms.

Most damage from chemicals derives from the activities of man, and much is the result of air pollution. Until recently, information about air-pollution effects on trees was limited to field situations—and primarily on attempts to relate visible injury to proximity and direction from recognized industrial sources. The papers by Hedgcock *(1914)* and Scheffer and Hedgcock *(1955)* are good examples of this approach.

Recognition of the magnitude and complexity of today's pollution problems, and of the possible indirect and chronic effects of pollution has spurred research efforts to clarify the effects of different pollutants, singly and in combination. From such research, a better understanding of pollution effects on oaks has begun to emerge.

Oaks vary markedly in their responses to different pollutants. For example, pin, scar-

Table 1.—*Summary of relative susceptibility of representative oak species to noninfectious disease agents*[1]

Species	Fire[2]	Drought	Ice	Frost	Flooding	Decline	Mineral Deficiency
White oak	3	2	3	2	2	2	—
Overcup oak	—	—	—	—	5	—	—
Bur oak	5	4	—	4	—	—	—
Swamp chestnut oak	—	2	—	2	3	—	—
Chestnut oak	2	4	—	4	—	—	—
Post oak	—	4	—	—	—	—	—
Scarlet oak	1	4	—	4	—	—	—
Southern red oak	2	2	—	—	—	—	—
Nuttall oak	1	—	—	—	—	—	—
Pin oak	1	—	—	—	4	2	2
Northern red oak	—	—	2	—	—	2	—
Black oak	2	3	—	—	—	—	—
Live oak	—	—	—	2	—	—	—

[1] Information obtained from many sources, most of which are cited in Hepting, G.H. 1970.
[2] 1. Very sensitive. 2. Sensitive. 3. Moderately resistant. 4. Resistant. 5. Very resistant.

let, gambel (*Quercus gambelli Nuth.*), and white oaks were found to be sensitive to ozone, while red and shingle (*Quercus imbaiuria Michy*) oaks were resistant; pin oak was sensitive to chlorine while red oak *Quercus rubra L.*, was resistant; and black oak *Quercus velutina Lam.*, was sensitive to 2,4-D while pin and red oaks were intermediate in sensitivity *(Jacobson and Hill 1970, Means and Lacasse 1969, Wood and Davis 1969).*

The above rankings were based on foliar symptoms. Little is known about effects that are less obvious. Such effects may be important. For example, marked abnormal tyloses formation and aberrant cambial and parenchyma production occurred in blackjack oak that survived 2,4-D poisoning. Even roots showed tyloses formation *(Marts 1947).* This latter response was utilized by Kuntz and Drake *(1960)* to control spread of the oak wilt fungus through root grafts of northern pin oak. Soil fumigants induced tyloses formation in injured roots and prevented movement of spores through vessels from disease to healthy trees.

Research with other tree species has revealed the fallacy of establishing "safe" concentrations for single pollutants. Ozone at levels below those causing symptoms on white pine has been shown to interact with SO_2 at relatively low levels to cause injury. Studies are needed to determine if pollutant mixtures are injurious to oak, and further to determine the environment-pollutant relationship.

Hepting *(1964)* has suggested that we must consider the effects of climate as it influences air-pollution phenomena in explaining the decline of northeastern hardwoods, including oaks. It is probable that indirect effects of chronic exposures to air pollutants will become more and more important. Scheffer and Hedgcock *(1955)* reported that *Armillaria mellea* (Fr.) Quel. was much more prevalent within areas damaged by SO_2 in the Columbia River Valley south of Trail, B. C., than in adjacent areas where trees were unaffected by the toxicant. This suggests that there may be an increase in the predisposition of trees to *Armillaria* in areas where pollution is increasing.

Irradiation has been studied as a source of injury to plants. Oaks apparently are severely damaged when subjected to continuous gamma-ray irradiation *(Sparrow et al. 1961).* Effects include abnormal and restricted development of vegetative parts and floral primordia, pollen abortion, and reduced seed production and seedling development *(Mericle et al. 1962, Stairs 1964a and b, Mergen and Stairs 1962).* In forests surrounding gamma fields, there was a continued decrease in species diversity, and severe ecological disturbances apparently would occur following accidental contamination of vegetation *(Woodwell and Rebuck 1967).*

Adverse climatic factors, both directly and indirectly, are important causes of noninfectious diseases of oak. Frost cracks have received attention for many years—indeed good accounts of the development of frost cracks were given by Hartig in 1894. Most research on frost cracks since then has come from Europe. In Hungary, damage to *Quercus cerris L.* was most severe on the largest stems and on trees with spiral grain, large crowns, and coarse branches *(Kondor 1966).* In Switzerland, most damage to *Q. robur L.* occurred on steep slopes where codominants were more susceptible than dominants *(Lamprecht 1950)*, while the worst sites for *Q. cerris* in Hungary were valleys and level lowlands *(Igmandi 1956).* In Belgium red oak was most susceptible when grown as isolated individuals or on edges of stands, especially on southeastern, southern, and southwestern aspects *(Malaisse 1957).*

In a Pennsylvania woodlot, Fergus *(1956)* found that frost cracks occurred on 17.5 percent and 22.3 percent of the white and scarlet oaks, respectively, and were most common on the larger dominants and codominants. Most frost cracks, like fire scars, occur on the lower 6 to 8 feet of trunk and can serve as infection courts for discoloration and decay fungi.

Late spring frosts are important in many areas, often causing severe damage over

large regions. Tryon and True *(1964)* discussed the nature of frosts and the relative susceptibility of Appalachian hardwoods. Oaks were considered moderately susceptible and white, scarlet, chestnut, and red oaks were ranked in that order (high to low). These authors recommended favoring resistant reproduction when regenerating stands and leaving at least a partial canopy if possible. Single-tree selection, small group-selection cuttings, and shelterwood cuttings were recommended.

In late May 1925 a severe frost injured tremendous numbers of white oak trees in the valleys and hollows of North Carolina *(Beal 1926)*. Over 3,000,000 feet of white oak died by the summer of 1926. White oak was more seriously affected than the red oaks because its leaves were less fully developed at this date. Beal indicated also that a widespread drought occurred in the summer of 1925.

Drought in 1925 was an important factor in the mortality of several oak species in North Carolina *(Hursh and Haasis 1931)*. During July and August only 11.6 percent of the normal average rainfall fell. Trees were seriously affected on ridges and upper slopes. In 1927 and 1929 no sign of damage occurred on trees that were symptomless in 1925. Half the trees that had drought symptoms in 1925 recovered but the rest had dead branches or had died. Chestnut oak suffered no permanent damage, but black, scarlet, and red oaks with severe leaf injury in 1925 were dead by 1929. Recovered trees showed little effect while those that died during the 4 years showed definite reductions in diameter increment during the period they were alive after the drought. True and Tryon *(1956)* and Tryon and True *(1958)* also correlated increment of dying scarlet oaks with precipitation deficits of the previous July-August period.

Hursh and Haasis *(1931)*, in their 4-year study of the 1925 drought, mentioned that severe late frosts occurred in April 1927. (At this time foliage of the red oak group probably would be susceptible.) They concluded that the combination of adverse environmental factors reduced the vigor of trees and predisposed them to attack by *Armillaria, Agrilus bilineatus* web., and long-horned beetles.

A relationship between drought and frost was shown by Bolycevcev *(1967)* in Russia. Injury to sapwood by frosts—ring rot—was greatest when the two preceding years had been droughty, and particularly when severe frosts were preceded by drought in the second half of the growing season.

True and Tryon *(1956)* associated the initiation of stem cankers on red, black, and scarlet oaks to the drought of 1953. A facultative fungus, *Fusarium* sp., grew from 18 percent of the isolation chips. *Fusarium* species have been associated with annual-type cankers of many tree species, and their incidence is often correlated with a stress factor.

The preceding examples indicate that serious problems may result from the cumulative effects of several adverse environmental factors and organisms of secondary action. Drought and frost are often associated with widespread declines of oak; and serious declines and mortality have resulted when these or other factors, singly or together, have occurred in association with severe insect defoliation. Thus, oak forests in the Save Valley of Switzerland declined when spring floods and silting were followed by defoliation by gypsy moth, *Porthetria dispar L.*, and attack by the fungus *Oidium quercinum* Thüm *(Barbey 1937)*. In Russia, a decline of oak was correlated with droughts of 1921, 1948, and 1956; followed by defoliation in 1927-1928, 1953, and 1959 by brown-tailed moths, *Nygmia phaeorrhoea* (Donov.), gypsy moths, and leaf rollers *(Minkevich 1962)*. The weakened trees were predisposed to vascular pathogenic fungi.

In the United States, oak frequently has exhibited decline on a massive scale. In general these occurrences have involved adverse environmental factors, particularly drought, defoliation by insects or hail, and finally attacks of weakened trees by root fungi and bark borers. Decline of oak over extensive areas of the Southeast occurred in the early 1960's. This area had suffered a series of dry years in the middle 1950's and

probably from attacks of the elm spanworm (*Ennomos subsignarius* [Hbn.]), and cankerworms *(Hepting 1970)*.

A decline of red and scarlet oaks occurred from Pennsylvania to North Carolina. An intensive study of this problem by Staley *(1956)* revealed that decline resulted from leaf roller defoliation aggravated by drought and late spring frost and by attacks of *Agrilus* and *Armillaria*. Essentially the same conclusions were reached by Nichols *(1968)*. Periodic declines of white oak in the Northeast have also followed similar combinations of adverse factors.

In Canada, severe deterioration of red oak was attributed to ice damage that reduced tree vigor and predisposed them to infection by *Armillaria (Dance and Lynn 1963)*. *Pseudovalso longipes* (Tul.) Socc. and *Diatrypella quercina* (Pers. ex. Fr.) Nits., two twig-blighting fungi, were associated with dieback of the crowns. Similar relationships of weakened trees attacked by twig cankering fungi were noted by Marshall *(1939)*.

THE LOOK AHEAD

The current emphasis on environmental quality will have an influence on factors that contribute to noninfectious disease of oak, especially to the declines. For example, restrictions on pesticides probably will increase the significance of defoliation as a stress factor, while increased controls of air pollution will probably lessen the importance of this agent as a possible stress factor.

Urbanization and resultant fragmentation of forest lands will increase the scope and magnitude of noninfectious disease problems. Research is needed to determine the roles of an ever-increasing array of stress factors. As the value of trees increases, foresters, pathologists, and others will be forced to understand more clearly the direct and indirect impacts of noninfectious agents.

The increasing frequency and the magnitude of the oak decline problem indicate that additional research effort ought to be focused here. The complexity of the causal relationships suggests that interdisciplinary efforts should be mounted to effect solutions of these problems. Knowledge is needed about the impact upon trees of defoliation, drought, frost, and air pollution, singly and in concert; and about the relation of this impact to susceptibility to organisms of secondary action. Such knowledge can be acquired only through a multidisciplinary approach.

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THE OAK WILT SITUATION

by WILLIAM H. GILLESPIE, *Administrative Assistant to the Commissioner, West Virginia Department of Agriculture, Charleston, W. Va.*

ABSTRACT. Although oak wilt has been studied for more than 30 years, there are many facets of the disease that are little understood. Continuing Federal-State cooperative studies are geared to predicting the overall effects of the disease on future forest-management programs, but much additional research is needed before present control programs can be expanded or discarded in a conscionable way.

OAK WILT, a vascular disease caused by the fungus *Ceratocystis fagacearum* (Bretz) Hunt, is potentially the most serious disease to affect oak trees in the 21 states where it has been found to occur. Widespread catastrophic losses have not yet been documented, although thousands of individual infection centers have been located by aerial and ground surveys in patchily infected forest stands. It is not known why the disease is limited to only part of the oak range in North America, but this phenomenon is thought to be related to ecological factors that directly or indirectly affect the pathogen or the vectors.

The origin of the disease remains a mystery. First described in Wisconsin in the early 1940's, it was almost immediately found in other states in the upper Mississippi Valley. By 1951 it had been found as far east as Pennsylvania, Virginia, and West Virginia. Estimates vary as to how long it has been present.

The pathogen is a vascular parasite that enters through any wound that ruptures the outermost xylem tissue. Single spores have been used to artificially initiate infection, although the incubation period seems to be shortened when a large number of spores are used.

Artificial inoculations have shown that the causal agent is virulent on at least 51 species of *Quercus* and several close relatives in the genera *Castanea*, *Lithocarpus*, and *Castanopsis*. It also causes defoliation of the Jonathan apple (*Malus*) and it has survived for some time in sassafras. The lack of immunity by oaks suggests that the range may possible expand in the future.

SYMPTOMS

Generally, oak wilt symptoms are distinctive and may be recognized readily from the ground or from low-flying airplanes.

The leaves of infected trees droop or wilt, and some turn bronze or brown in color. They then fall from the tree. Often the leaves fall while still green, and in other instances a small green island is left

at the base of each. Sometimes one or more branches will remain green. About 6 weeks after defoliation, the larger branches produce sucker sprouts. Late fall infections may show no indication of the disease other than a premature fall coloration. Some of these trees refoliate normally the next spring and then produce symptoms, while others die over winter without producing visual symptoms.

Disease development often varies greatly between individuals, and it differs markedly between members of the red and white oak groups. Red oaks are thought to be more often infected. They exhibit symptoms over the entire tree, and the tree normally succumbs in 1 year. The foliar symptoms of white oaks, in contrast, are often restricted to localized branches, and they sometimes appear only during the season of infection.

In some instances white oak trees are able to "bury" the fungus with overgrowths of new wood. These hidden infections are seldom discovered unless the tree again develops foliar symptoms, as has happened, after a lapse of as much as 7 years. The role of such reservoirs of infection in continuation of the disease has not yet been fully accessed. Young chestnut oak trees may wilt and suddenly drop all of their leaves in a pattern reminiscent of young red oak, but older individuals of the same species may take somewhat longer—as is true for the white oak group as a whole.

The question about whether infected red oaks ever recover is often asked, but research has shown that the outer vessels of infected trees are plugged with gums and tyloses as much as 4 days before foliar symptoms develop; thus the disease is practically irreversible before the first leaf falls.

SPREAD

Oak wilt spreads both overland and underground. Overland dissemination is thought to be primarily due to certain sap-feeding beetles belonging to the family Nitidulidae, although *Pseudopityophthorus*, a genus of oak bark borers, has also been incriminated. The role of birds, squirrels, and other insects has been extensively discussed in the literature, but confirmation is lacking.

Nitidulid beetles are prime suspects in much of the northern part of the range because of their intimate relationship with the development of specialized fungal cushions. Bark borers are thought to be more logical vectors in southern areas, such as in Missouri, where the fungal cushions do not occur in abundance. These cushions begin with the development of large amounts of mycelium in the vessels. This mycelium then migrates intracellularly to the cambium, where it forms "mats" between the bark and wood. Endoconidia are produced in abundance on the mats as the bark is slowly cracked by the growth of opposing fungal cushions. This creates a cavity over the mat. A characteristic odor from the mat attracts insects which, while feeding on the self-sterile fungus, pick up conidia, both internally and externally, and later transport them to other mats where conidiation ensues and fertile perithecia result. Either ascospores or conidia can cause infections.

The fungus has been shown to move underground through natural root grafts between diseased and healthy trees. Starting with an initial infection, the disease, particularly in shallow or sandy soils, moves progressively outward in a more or less concentric pattern, although on steep hillsides the disease often follows the contour. Root-graft spread is most prevalent in Midwestern States, but it does occur to some extent wherever the disease has been found. Grafting is infrequent between members of the white and red oak groups, but it is known to occur.

CONTROL PROGRAMS

Oak wilt control programs have been characterized by small-scale experiments in some states and by statewide efforts in others. Some Eastern States conduct their programs in cooperation with the USDA Forest Service under auspices of the Forest Pest Control Act of 1947. In the upper Midwestern States, the disease was thought to be too widespread, when initially discovered, to be controlled.

For example, experiments in Wisconsin indicated that the rate of progress of the

disease was such that virtually all oak would be removed within 75 to 100 years. In some states, control was attempted and abandoned. In others, control was not attempted because of financial or other problems.

Two exceptions are Pennsylvania and West Virginia, where statewide control programs have been vigorously pursued for years. The control techniques used in these states are quite different, yet both have as their goal the elimination of the mat-like fruiting structures as sources of inoculum.

Before embarking on systematic control programs, discussion by Federal and State officials in the above-mentioned states revolved around whether or not the costs could be justified. Also, as the potential losses and the chances of control were not immediately known, it became imporant to decide whether controls based upon admittedly insufficient knowledge should be attempted. This decision had to rest upon the danger involved if control should be delayed, because there was the presumed potential of the disease for eliminating the number one timber tree in the region. Consequently it was decided to move into control as rapidly as possible, but to continually adjust or modify the control program as new information became available.

The techniques used in the control programs varied from the beginning. As Federal funds were being used in several of the programs, a cooperative study with four states was initiated in 1958 to check on the effectiveness of the differing techniques being used and the economic implications of each. This study eventually became an appraisal of Oak Wilt Control Programs in Pennsylvania and West Virginia.

In Pennsylvania, all diseased oaks and healthly trees of the same species group within 50 feet of diseased trees are felled, and the stumps are treated with Ammate. The diseased trees are felled to hasten drying, which in turn lessens mat formation; the healthy trees are removed to prevent possible spread through root grafts.

The West Virginia technique involves chopping a girdle to the heartwood at a convenient height. The bark is then removed from the girdle to the soil line. This hastens drying of the tree as well as allowing for a rapid ingress of competing fungi such as *Hypoxylon*. Infection centers are located from low-flying airplanes in both states. Nontreatment or check plots were located in Maryland and Kentucky.

The initial study was conducted from 1958 through 1963, and the results indicated a reduction of diseased trees on plots treated by both methods. More importantly, the data showed that the disease intensified with time on untreated plots. As the different treatments and untreated checks were segregrated by state, ecological factors could not be assessed; and this fact caused reservations about the validity of the study. A second study, designed to remove past criticisms, is now being conducted. The results of the first few years will be available soon. One very important aspect of this concinuing control appraisal is the surveillance of quadrangle-sized plots instead of the more limited areas previously used.

Data compiled by West Virginia workers indicate that there is very little cost differential between the Pennsylvania and West Virginia treatments if the tree location is first plotted on topographic quadrangles and if only one trip is made to each infection center. There is, however, an overall cost differential due to the use of chemicals and to the greater number of trees cut in the Pennsylvania method.

RESEARCH NEEDED

The future of all oak wilt control programs hangs on research—research on the effectiveness of present techniques and research on untried comparisons. There is also a great need for research into the ecological aspects of the disease. For example, why is the problem restricted to only a part of the overall range of oak in North America? Is this a climatic limitation or is it correlative to vector distribution?

There are several holes such as this in our knowledge. For example, the causal fungus varies in appearance, physiological activity, and possibly in virulence. Thus, can we develop a system of continued monitoring of the organism to forecast the

appearance of new and more virulent strains, or strains adaptable to different environmental conditions, which could conceivably extend the present geographic range?

It is doubtful that the fungus is limited to distribution by a single vector, or even to two or three; but present knowledge on this matter is inconclusive.

The role that antibiotics and systemic fungicides will ultimately play in the treatment of infected trees in residential or other high-value properties needs to be more adequately evaluated. Will soil sterilants be developed that will inhibit root-graft transmission in the Appalachians as methyl bromide apparently does in the sandy soils of Wisconsin?

What are the respective roles of spring and fall mats? Is fall mat production important? If so, does the infection occur so that the fungus overwinters in the host? Or do the spores overwinter in the soil, in or on insects, etc.?

QUESTIONS, QUESTIONS

Natural regeneration in disease centers does not seem to be a problem in the Appalachians, but perhaps not enough time has elapsed to show certainly. Will this situation change when infection centers expand and unite so as to remove oak from acres in contrast to the present small centers? What is happening on large infection centers in the Midwest? Will the disease ultimately cause a degeneration of stand productivity throughout its range, even though there may not be any discernable influence on the establishment, survival, and development of individual oaks?

Will the mere presence of the disease continue to inhibit the exportation of oak logs to foreign countries? Will it be possible to exploit the fumigation treatments worked out by the USDA Forest Service as a technique to obviate present quarantine restrictions?

Are there unrecognized inoculum sources? If so, what are they, and how is the fungus transferred?

What factors govern the establishment of the disease in an otherwise healthy tree? Do we understand the overall ecologic factors that influence the suscept-pathogen-vector relationships? Do we really understand the disease as it exists in nature?

There are dozens of similar basic questions that need to be asked and answered before we can assess the true potential of oak wilt. Will the fact that the requirements for successful transmission are very exacting and that the requirements may vary from region to region work to the detriment of control activities? Perhaps different control measures will need to be developed that will consider ecological peculiarities.

Perhaps we will never know the answers to all the questions. Perhaps the disease will silently disappear just as it arrived. Or perhaps it will intensify and devastate the resource before we can solve the riddle or develop the necessary control programs. It is ironic, but the overall pace of research effort has slowed in recent years. Can it be accelerated? Has it slowed because the easier answers have been found? Or is it because we have tired of the problem and have not yet been sufficiently remotivated? Could it be that many of the past problems have been solved in the laboratory, while most of the current questions will be answerable only in the field?

The evaluation of oak wilt intensities and the location of diseased trees through use of aerial surveying techniques is a field of recent interest. Much can be said for color and for infrared photography, but these are as yet strictly experimental and cannot be used on routine programs.

One problem with aerial techniques, both in surveying for oak wilt and for beetle-damaged pines, is that more or less overlapping contour flying is necessary. It has been shown that it is virtually impossible, at altitudes of 500 feet above the terrain and at speeds of 90 miles per hour, to locate single trees or even clumps of two or three infected trees more than ¼ mile distant. Therefore, surveys flown on 1 mile grids, or flown at 500 feet above the highest terrain, or flown at speeds in excess of 100 miles per hour, are suspect. Even if flown the exact same way every time, they will not give similar results, especially if new or

untrained personnel are used. In addition, grid flights never give 100-percent coverage, and they should not be reported as such.

WHAT NEXT?

In summary, the oak wilt situation is now virtually static; and program directors are badly in need of research information. It is anticipated that within the next 2 years the cooperative Federal-State analysis will provide guidance on how to proceed with present programs.

But, if the analysis indicates that control efforts should cease, then the true problem will rapidly emerge. Will we be able to develop information on how to predict the total effect on forest management in time? Will we be able to recommend harvesting practices that will slow the disease? Will we be able to develop a statistical model to predict future intensities instead of relying upon deterministic calculations?

Oak is such a valuable resource that every possible effort must be expended to prevent its loss if the loss indeed seems imminent. The surveys and resultant control programs may have to be extended indefinitely. We just do not know at present. We hope some sort of biological control will finally be developed on the basis of complete ecological data. Only then will those entrusted with the management of our forest resources for future generations be able to relax.

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INSECT DAMAGE TO OAKS

by CHARLES O. REXRODE, *Principal Entomologist, Forest Insect and Disease Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Delaware, Ohio.*

ABSTRACT. In terms of mortality caused by insects, defoliators are the most serious enemies of oaks at the present time. An oak leaf tier, *Croesia semipurpurana*, is one of the principal defoliators of trees in the red oak group. Oak leaf rollers, primarily *Archips semiferana*, have been responsible for widespread mortality in white and chestnut oaks. Defoliation by the gypsy moth, *Porthetria dispar*, could become the major insect problem in the Appalachian Region and possibly throughout the Eastern United States. Economically, wood borers may be the most important at present.

INSECTS ARE the most numerous animals living in a forest, and more than a thousand different insect species feed on oaks *(Metcalf and Flint 1962)*. However, we are interested only in those that cause important damage. Only a few groups of insects have a significant impact on the oak resource: the leaf feeders (defoliators, skeletonizers, and miners); the borers (bark, phloem, wood, root, twig, shoot, and acorn borers); the sucking insects; and those insects that cause indirect damage, such as vectors of disease-inducing organisms.

The discussion will center on damage and impact by the most important defoliators and borers affecting the five upland oaks. Present and future needs for control of these insects will be discussed from both a forester's and entomologist's viewpoint.

DEFOLIATORS

In mortality caused by insects, defoliators are the most serious enemies of the oaks at present. An oak leaf tier (*Croesia semipurpurana* [*Kearf*]) is one of the principal defoliators of trees in the red oak group (fig. 1 and fig. 2). It has intensified during the past 10 years and is now one of the primary factors causing mortality or initiating decline in oak stands.

Staley *(1965)* concluded that defoliation by *C. semipurpurana* was the primary causal factor in the decline of red and scarlet oaks in Pennsylvania, Virginia, and West Virginia during the 1950's. This insect has been collected in many states from the East Coast to Texas and Minnesota, and it probably occurs throughout the range of the upland oaks.

Beckwith *(1963)* described its stages and seasonal development in Connecticut. It overwinters in the egg stage on small branches of the host tree. Larvae hatch about mid-April and migrate to expanding buds. They feed on the foliage until late May. Pupation occurs primarily in the litter beneath the trees, and adults can be seen in early June. There is one generation per year.

In areas of Pennsylvania and West Virginia where oak mortality is caused by insect defoliation, *C. semipurpurana* com-

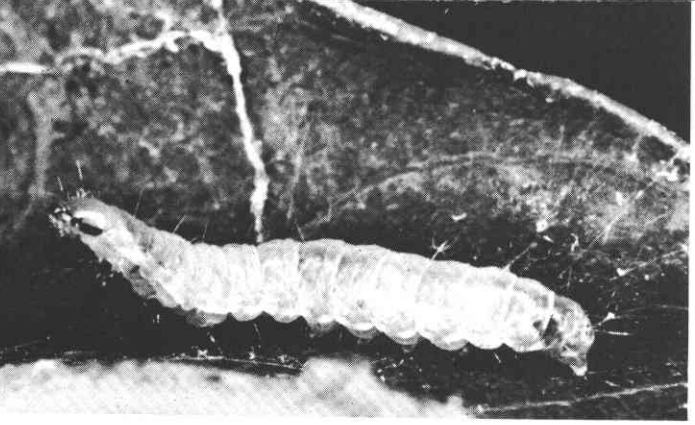


Figure 1.—An oak leaf tier larva *(Croesia semipurpurana).*

monly causes 60 to 90 percent of the total defoliation. Several species of leaf rollers normally found associated with this oak leaf tier occasionally contribute substantially to defoliation.

Oak leaf rollers, primarily *Archips semiferana* (Wlk.), have been responsible for high mortality of white and chestnut oaks. In 1968-70, *A. semiferana* was responsible for mortality ranging from 5 to 98 percent in oak stands on 175,000 acres in Pennsylvania *(Nichols 1970)*. The oak leaf rollers have life cycles similar to that of the oak leaf tier *C. semipurpurana.* However, leaf roller damage is limited to higher elevations while the oak leaf tier does most of its damage at lower elevations and in river drainages.

The gypsy moth (*Porthetria dispar* L.) could become the major insect problem in the Appalachian Region and possibly throughout the Eastern United States. Oaks

Figure 2.—Larval webbing and feeding by the oak leaf tier.



are among its favored food plants. It has one generation a year, and its life cycle is similar to that of the oak leaf tier. It overwinters as eggs are deposited on almost any object. The larvae hatch in late April and early May and feed on foliage until late June or early July. Adults are present from early July to late August.

About 8,000 acres of oak and other tree species were completely defoliated by the gypsy moth in Pennsylvania in 1970 *(Nichols 1970)*. Estimates are that 1 million acres of forest land in Pennsylvania are infested by the gypsy moth. In New Jersey, in 1968-71, over 1 million oaks were killed on 18,000 acres as a direct result of gypsy moth defoliation *(Kegg 1970)*.

IMPACT OF DEFOLIATION

The effects of defoliation are obvious because the leaves synthesize the food needed by the plant for sustenance and growth. The degree to which an oak is injured depends on the extent of defoliation, the season of year, and the frequency of successive defoliations. Severe defoliation reduces the production of wood, especially when it occurs early in the growing season. Successive annual defoliations cause branch dying and tree mortality.

Results of studies by Nichols *(1968)* on oak mortality in Pennsylvania show the effects of defoliation. He found that 2 consecutive years of 60- to 100-percent spring defoliation caused mortality. Only rarely did mortality result from one heavy stripping preceded by several years of moderate defoliation. Continuous moderate defoliation did not kill trees, but it started their decline. A year of moderate defoliation reduced radial growth by 20 to 30 percent. But 1 year of heavy spring defoliation resulted in a 40- to 70-percent growth reduction.

Widespread mortality of tree species in the red oak group has occurred on nearly 500,000 acres in Pennsylvania and West Virginia since 1953, and sawtimber losses have ranged from 3,000 to 7,000 board feet per acre. Areas of mortality have ranged in size from 30 to 15,000 acres.

W. P. House *(1955)* appraised damage caused by the gypsy moth in New England from 1933 to 1952. He found that, on the average, every acre of oak type reported as 75 or 100 percent defoliated suffered mortality of 19 percent of the volume.

During a 10-year period (1912-21), Baker *(1941)* found that there was 30 percent mortality of oaks where defoliation by gypsy moth averaged 37 percent. Growth increment among oaks 81 to 100 percent defoliated was about half that of normal.

In appraising the effects of defoliation, the secondary barkmining insects are important factors in determining the ultimate damage to the stand.

WOOD BORERS

Although the borers are listed here as the second important group of insects affecting the oaks, economically, they may be the most important. At least 30 species attack living or recently killed oaks in the Appalachians. Perhaps the most important species damaging the upland oaks are the *Goes* borers, the Columbian timber beetle (*Corthylus columbianus* Hopk.), the red oak borer (*Enaphalodes rufulus* [Hald.]), and the carpenterworm (*Prionoxystus robiniae* [Peck]).

The injuries in wood ordinarily are not extensive enough to produce mass symptoms in a forest. Only rarely are there external signs of attack on a tree or log. On individual trees, evidence of insect attack consists of dead areas that become open cavities, small holes, distortions in the bark pattern and cracks exuding sap and extruded wood fibers. Observations normally must be made on split, sawed, or peeled portions of the wood.

IMPACT OF BORERS

Wood-boring insects are responsible for a large portion of the poor-quality timber in our hardwood stands (fig. 3). Direct damage results from their boring and associated stains; indirect damage is done by wood-decaying fungi gaining entrance through the borings. Loss of growth has not been determined, and mortality is rare. Accurate appraisals of damage to the value and quality of lumber and veneer are at present lacking. The insects responsible for

the red oak group should be reduced to a minor component of the stand. Red and black oaks should be left in preference to scarlet oak. Depending on other management considerations, clearcutting is probably the best treatment for large areas of mortality, especially where scarlet oak predominates. White pine and white oak should be encouraged.

Silvicultural control also shows promise for reducing future damage by wood borers. Preliminary results of recent studies suggest that modified cutting practices can significantly affect wood borer populations.

THE FUTURE

We should consider not only the problems we face today, but also our needs for the future. We, as forest entomologists, often think of the study of insects in terms of a zoological science and forget that it is a forestry science as well. The ultimate objective of the forest entomologist should be to discover how to prevent insects from causing economic damage to forests. Control prescriptions must be developed for prevention rather than cure.

Too many entomologists have become detached from the problems of forest management. There must be more integration of entomological principles into oak management programs. Management guidelines for our upland oaks should be developed through the cooperative efforts of practicing foresters, research foresters, entomologists, pathologists, and economists.

At present, the full biological and ecological impact of insects on oak forests is not known. When we have an insect outbreak, too often the decision for direct control is based on the abundance of the insect pest that will apparently cause the death of a large volume of timber. But it is not enough to look at the insect and host alone—we must look at the entire forest.

Enlightened insect control, to be both effective and lasting, will require a thorough understanding of the biology of the pest. In addition, comprehensive damage and hazard appraisals will be needed, including evaluation of pest impact on stand composition, release, succession, age distribution, and other factors of stand ecology.

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DISCOLORATION & DECAY IN OAK

by ALEX L. SHIGO, *Research Plant Pathologist, Northeastern Forest Experiment Station, Forest Service, USDA, Durham, N. H.*

ABSTRACT. Diseases that result in discoloration and decay of wood are major problems affecting all species of oak. Wounds often start the processes that can lead to these diseases. The type and severity of the wound, the vigor of the tree, the environment, and the aggressiveness of microorganisms that infect are some of the most important factors that determine the nature of the disease. Decay following fire wounds and decay in sprout stems have been the major defects in oak. Now discolorations and other defects once considered minor are becoming more important.

THE OAKS ARE important not only in the United States, but also in many other countries. Because of their importance in central Europe, where forest pathology emerged as a science, the species of oak there were among the first trees studied by early forest pathologists. Some of the first studies by these investigators were on decay, which was considered a major problem. Studies on decay by Robert Hartig at that time set firmly the foundation for forest pathology *(Hartig 1878, 1894)*.

When forest pathology began to emerge in the United States at the turn of the 19th century, decay was considered a major problem in need of research attention. And decay in oak was high on the list of priorities. George H. Hepting was the first to develop a sound research program on decay in oaks. Some of his early studies were made with George G. Hedgcock, who was one of the first forest pathologists in the United States. In 1935, Hepting published on decay following fire in young Mississippi delta hardwoods *(Hepting 1935)*. This important work set the stage for many decay studies that were to follow.

Many investigators have since studied decay in oak, and many valuable contributions have been made; but the results of studies by George H. Hepting, E. Richard Toole, and Elmer R. Roth still account for most of our present information about decay in oak. A detailed literature review and brief accounts of all the important discoloration and decay studies on the major species of oak in the United States are given by Hepting *(1970)*. This publication will give anyone interested in discoloration and decay in oak an immediate exposure to all the important literature and to an accurate summary of the information available. Because this publication exists and is readily available, I will only outline briefly the information given by Hepting and will present some other information about discoloration and decay in oak.

DISCOLORATION AND DECAY PROCESSES IN GENERAL

Diseases that result in discoloration and decay of wood are major problems affecting all species of oak. Wounds often start the processes that can lead to these diseases. The type and severity of wound, the vigor of the tree, the environment, and the aggressiveness of microorganisms that may infect are some of the most important factors that determine the nature of the disease.

The events that follow wounds on trees of high vigor are different from those that follow wounds on trees of low vigor. Trees have repair systems that heal wounds. And most wounds do heal. The processes that can result in discoloration and decay start when the force of the repair system is overcome by the force of invading microorganisms. Anything that lowers the vigor of the entire tree or a portion of it will then lower the force of the repair system.

Wounds on low-vigor trees are the most serious problem.

The many species of oak in the United States grow on a wide variety of sites. Some of these sites are very poor, and the trees on them are low in vigor. Add to this the declines, diebacks, oak wilt, insect defoliations, insect borers, droughts, and many other problems that reduce the vigor of the trees; then add further wounds caused by fires, logging operations, animals, and other agents: and it seems a wonder that oak can even survive at all.

Oaks are different in many ways from the northern hardwoods—beech, birch, and maple. A few of the important differences center about the true heartwood core and the ring-porous wood in oaks. These differences play an important part in the way discolorations and decays develop in oak. The heartwood is impregnated with many substances that make it resistant to attack by many microorganisms. Yet some microorganisms under certain conditions can infect heartwood. The vessels in oaks often form tyloses in response to injury. These tyloses block the passage of many microorganisms. Yet some microorganisms invade tissues containing tyloses.

Discoloration

Wounds may expose sapwood or both sapwood and heartwood in oaks. The depth of the wounds may then determine whether microorganisms that attack sapwood or heartwood will infect. The living cells in the sapwood elicit a dynamic response, while the dead cells impregnated with various substances in the heartwood elicit a passive response.

The response of the sapwood to wounding in oak is not so different from the response to wounding of the wood in a northern hardwood. The first events that follow wounding of the sapwood are chemical responses, in which cellular materials are altered as a result of exposure to the atmosphere. The altered materials resulting from these processes can impart a slight discoloration to the wood. When the wound remains open and conditions for infection by microorganisms remain favorable, microorganisms infect and the discoloration of the wood intensifies.

The discolored wood that results after wounding appears similar to heartwood and it is often called a type of heartwood: ". . . an alternation of the wood exactly similar to normal heartwood formation also occurs as a pathological phenomenon in the vicinity of wounds" *(Büsgen and Münch 1931), page 126)*. Hart *(1965)* showed that discolored sapwood was higher in moisture content, ash content, and pH, and was lower in its cold-water-solubility than was heartwood. The Committee on Nomenclature *(1964)* defined heartwood as:

> . . . the inner layers of wood which, in the growing tree, have ceased to contain living cells and in which the reserve materials (e.g., starch) have been removed or converted into heartwood substances. It is generally darker in color than sapwood, though not always clearly differentiated.

This definition is based on three major conditions: cell death, depletion of nutrients, and deposits in the cells; and a minor condition, darkening of the tissues. These four conditions occur in discolored wood also, depending on the stage of development. The processes that resulted in the discolored wood may continue as micro-

organisms invade further, and decay may result. This does not occur in heartwood that is not injured and where no microorganisms are involved. This is an important difference between heartwood and discolored wood *(Shigo 1967)*.

Heartwood may also discolor after injuries. Insect galleries are commonly surrounded by discolored heartwood.

Discoloration following increment borings developed slower in oaks *(Hepting et al. 1949)* than in other hardwoods *(Lorenz 1944)*. However, Toole and Gammage *(1959)* pointed out that the discoloration resulting from wounds made in the spring in Nuttall oak extended vertically farther than in four other species of trees (eastern cottonwood, green ash, sweetgum, and sugarberry). Following such wounds the discoloration developed as a streak along the sapwood-heartwood boundary *(Shigo and Sharon 1968)*.

In the past, discolorations in oak were not considered important defects. Slight discolorations did not reduce the value of wood used for railroad ties, construction materials, and the like. When defect-free wood was wanted, there was always a large supply to choose from. Now the situation is different. Discolorations in oak are becoming an important problem as more high-quality products are made and as more oak is used for veneer. For example, wooden floors, furniture, wall panels, and many other products must be free of discolorations to satisfy the modern market. We know relatively little about discolorations in oaks. We need to know more.

Decay

No doubt more is known about decay in species of *Quercus* than in species of any other genera of hardwood trees. The wood has been used primarily in products where strength over a long period is essential. Anything that caused a reduction in the strength of the wood caused problems. No one wanted a house, a ship, a railroad bed, or a bridge built with wood that might fail under stress, use, or time.

Although in many cases the decay recognized by most people was decay of the product, this still called attention to decay. And, when enough pressure is exerted by people, some action must follow. In the United States, this pressure began to build early in the 20th century. The vast forests of oak in the Appalachian Region were considered of high value. Information was needed to help predict the development of decay over large areas and to estimate internal defects associated with external indicators. At the same time oak was receiving this attention, other hardwoods in the northeastern United States were being girdled in favor of the conifers.

Early studies carried out by Hepting and Hedgcock *(1935a, 1935b, 1937)* on 5,882 trees cut from 1924 to 1928 in the Appalachians showed that 77 percent of all the defects were due to butt rot, 2 percent were due to top rot, and 3 percent were due to other defects. And 94 percent of the butt rot was due to microorganisms entering through fire wounds. These studies showed clearly the extreme importance of fire wounds.

Fire Wounds

The amount of butt rot in any area depends on the history of fire in that area. Information for predicting cull following fire in Appalachian oaks is given by Hepting *(1941)*. The predicting equation for individual trees was based on the width of the basal wound 12 inches above ground and the age of the wound. The variation in the amount of decay associated with the wounds was due to the different fungi invading the wood. *Stereum frustulosum* and *Hydnum erinaceus* were the most common fungi associated with advanced decay.

Hepting gives also a good account of a succession of decay fungi following fire wounds *(Hepting 1941)*. *Schizophyllum commune*, *Panus stipticus*, *Daldinia concentrica*, *Nummularia* sp. (*Hypoxylon*), and some species of *Stereum* and *Polyporus* produced sporophores on the wound surface the first summer after the fire. The next summer *Stereum rameale*, *S. lobatum*, and *Lenzites betulina* produced sporophores, and the third year sporophores of *P. gilvus* began to appear. The heartrotting fungi then followed.

For oaks in the Southern bottomland, Kaufert reported on decay following fire in 1933 *(Kaufert 1933)*. Of 261 red oaks examined in a 70-year-old stand, 72 percent had decay. Later Toole and Furnival *(1957)* and Toole *(1959)* extended the studies of Kaufert and Hepting to include larger trees, other species, and additional information on the rate of decay induced by various species of fungi.

Toole *(1959a)* also gave information on a succession of fungi infecting fire wounds. His observations were similar to those of Hepting *(1941)*. Toole *(1959a)* stated that, although 30 species of fungi were identified, only 5 species were associated with half of the rot: *Pleurotus ostreatus*, *Hydnum erinaceus*, *Polyporus fissilis*, *P. lucidus*, and *P. sulphureus*. In a recent study on decay in upland oak stands of Kentucky, Berry *(1969)* found that 26 percent of 490 trees had fire wounds and that most of the advanced decay was caused by two species of fungi: *Poria cocos* and *P. nigra*. *Poria cocos* was limited to the butt, while *P. nigra* invaded the butt and trunk.

Although better methods for fire prevention during the last decade have reduced considerably the number of new fire wounds, there are still many trees in our forests that have active decay columns associated with old fire wounds. The forester still needs all the information he can get on estimating defect associated with fire wounds. Because the history of fire will be different from area to area, and because different aggressive fungi will be active in the different areas, the information must pertain to specific areas to be useful.

Rot in Sprout Oak

In 1936 Elmer R. Roth and Bailey Sleeth pointed out in a preliminary report *(Roth and Sleeth 1936)* that a very high percentage of decay in sprouts in fire-free oak stands was traced to the parent stump. *Stereum gausapatum* was the principal fungus associated with the decay. In 1937, Hepting and Hedgcock stated that there was more decay in stump sprouts than in seedlings and seedling sprouts *(Hepting and Hedgcock 1937)*. Subsequent work gave valuable information on butt rot in unburned sprout oak stands *(Roth and Sleeth 1939)*, on wounds and decay caused by removing larger companion sprouts of oaks *(Roth and Hepting 1943a)*, and on origin and development of oak stump sprouts as affecting their likelihood to decay *(Roth and Hepting 1943b)*.

Recommendations for managing oak sprout stands came primarily from these studies. This work is summarized by Hepting and Fowler *(1962)*. To minimize decay in sprouts, they give three general recommendations: (1) favor low-origin sprouts; (2) favor those that are separated from a companion sprout by a low U-shaped crotch; and (3) make a flush saw cut when removing a companion sprout. Hepting and Fowler *(1962)* diagrammed the procedures.

The paper by Roth and Hepting *(1969)* on the prediction of butt rot in newly regenerated sprout oak stands culminated the series of sprout oak studies begun in the early 1930's. This study showed clearly that the information gained from past studies was indeed applicable. The authors also pointed out reasons why decay in sprouts will be on the decrease in future stands. The modern chainsaw makes it possible to cut trees low on the stump. Fewer small trees are being cut for fuelwood, and large stumps do not sprout as readily as small stumps. Burning after clearcutting insures low-origin sprouts. And—most important—the information gained from all the studies on sprout stems has found its way into practice.

Root Rots

Hepting *(1970)* divides the root rot into three groups:

> (1) Those few minor rots not caused by Hymenomycetes; (2) those Hymenomycetes which play a secondary role in the death of trees and cause little butt rot; and (3) those which play a secondary role in tree death, but can rot not only the woody tissue of roots, but can cause extensive butt rot.

Phytophthora cinnamomi and *Phymatotrichum omnivorum* are in the first group. They are most active on roots of young nursery seedlings.

Armillaria mellea and *Clitocybe tabescens* are the major fungi of the second group.

They are active on roots of oaks of all ages. Actually, little is known about the role of *A. mellea* in the death and decay of roots.

The major fungi in the third group are *Polyporus berkeleyi, P. curtisii, P. dryadeus, P. lucidus, P. spraguei,* and *P. sulphureus.*

Root rots in oak may be more important than is now recognized. More studies that entail digging and dissecting roots of mature trees must be done.

Top Rots

Hepting, Garren, and Warlick *(1940)* studied the external features correlated with top rot in 333 Appalachian oaks. Poorly healed large branch stubs were the major infection courts correlated with top rot. Roth *(1948)* pointed out that the decay hazard increased with the width of the wound. If pruning is to be done, he recommended that the branch should be less than 1.5 inches in diameter when cut. *Stereum gausapatum* and *S. rameale* were isolated commonly from the decay associated with large open branch wounds.

Canker Rots

The principal decay fungi that incite cankers on oaks are *Polyporus hispidis, Poria spiculosa, P. laevigata,* and *Irpex mollis (Sleeth and Bidwell 1937, Campbell and Davidson 1942, Roth 1950, and Toole 1955, 1959b). Roth (1950)* points out that there was no relation between tree vigor and the occurrence of *Irpex mollis* cankers, since they were found on both slow-growing and fast-growing oaks on both good and poor sites.

Decay Fungi

As studies on decay in oaks progressed, it became necessary to know more about the fungi associated with the decays. It became evident that more information was needed on the sporophores and on the identification of the fungi in culture. The outstanding investigators who worked on the sporophores were Lee Oras Overholts, who wrote "The Polyporaceae of the United States, Alaska, and Canada" *(Overholts 1953),* and Josiah L. Lowe, who wrote "Polyporaceae of North America: The Genus *Fomes*" *(Lowe 1957)* and many other works, especially on the genus *Poria.* The outstanding investigators who worked on the cultural characteristics of the decay fungi were Ross W. Davidson *(Davidson et al. 1938); Davidson el al. 1942;* and *W. A. Campbell (1938).*

CONCLUSION

The great amount of work done on decay in oak by only a few dedicated researchers is very impressive—especially when you consider some of the conditions they had to work under. Their work set a firm foundation for work that must now follow.

The changing world is changing priorities constantly. New problems are demanding new solutions. More emphasis is being placed on individual trees, on discolorations, and on many other defects considered minor in the past, but now of major importance. More people are looking at trees. There are green belts, recreation sites, street trees, backyard trees, and watershed trees—and the list goes on and on. In the future it will not be so important where the tree is, but the fact that the plant is a tree. And, in the future, trees will need all the help they can get to survive.

We are now in a position somewhat similar to the one that started in the early 1930's. More information will be needed on the processes that result in discolorations and decays in individual trees. More information will be needed on better ways to prevent and stall the processes that lead to these defects. Now is the time to take the next step.

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DETERMINING THE RATE OF VALUE INCREASE FOR OAKS

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ABSTRACT. A method used to develop rate of value increase is described as an aid to management decision-making. Regional rates of value increase and financial maturity diameters for ten species common to the oak-hickory type are outlined, and the economic principles involved are explained to show how they apply to either individual trees or stands.

AN IMPORTANT objective in forestry is to earn an acceptable return on capital invested in growing timber. Once he has decided on the level of return he considers acceptable, a timber grower needs a way to measure his success in attaining it. Rate of value increase (RVI) provides him with a way to measure his success and, when used with proper silvicultural methods, helps him to attain it.

Rate of value increase is, simply, the rate at which trees or stands increase in value. But it is also a lot of other things. To those in the timber-growing business it is a means for attaching a dollar sign to the results of all the complex and interacting biological factors that make up tree growth; a crosswalk between silvicultural and economic principles; a basis for deciding which trees or stands to cut and when to cut them. Even if a timber owner chooses not to cut his timber, he can use rate of value increase to judge his preferred objectives in terms of the timber returns he has elected to forego.

A method used to compute the rates of value increase and to determine the financial maturity diameters for several species commonly associated with the oak-hickory type is described here. It is based largely on research work previously reported in Northeastern Forest Experiment Station Research Papers *(Trimble and Mendel 1969; Mendel and Trimble 1969).* Our effort here is concerned primarily with the application of these results to individual trees and stands of timber.

METHODOLOGY

Computation of the rate of value increase is based on the relationship between the present value and the prospective value 10 years hence, as indicated in the compound interest formula

$$(1 + r)^n = \frac{V_n}{V_o}$$

where r is the rate of interest, n is the time period, V_n is the prospective tree value or stand value, and V_o is the present tree value or stand value.

Say we had a 3-log 20-inch red oak that had a grade 2 butt log. Its present

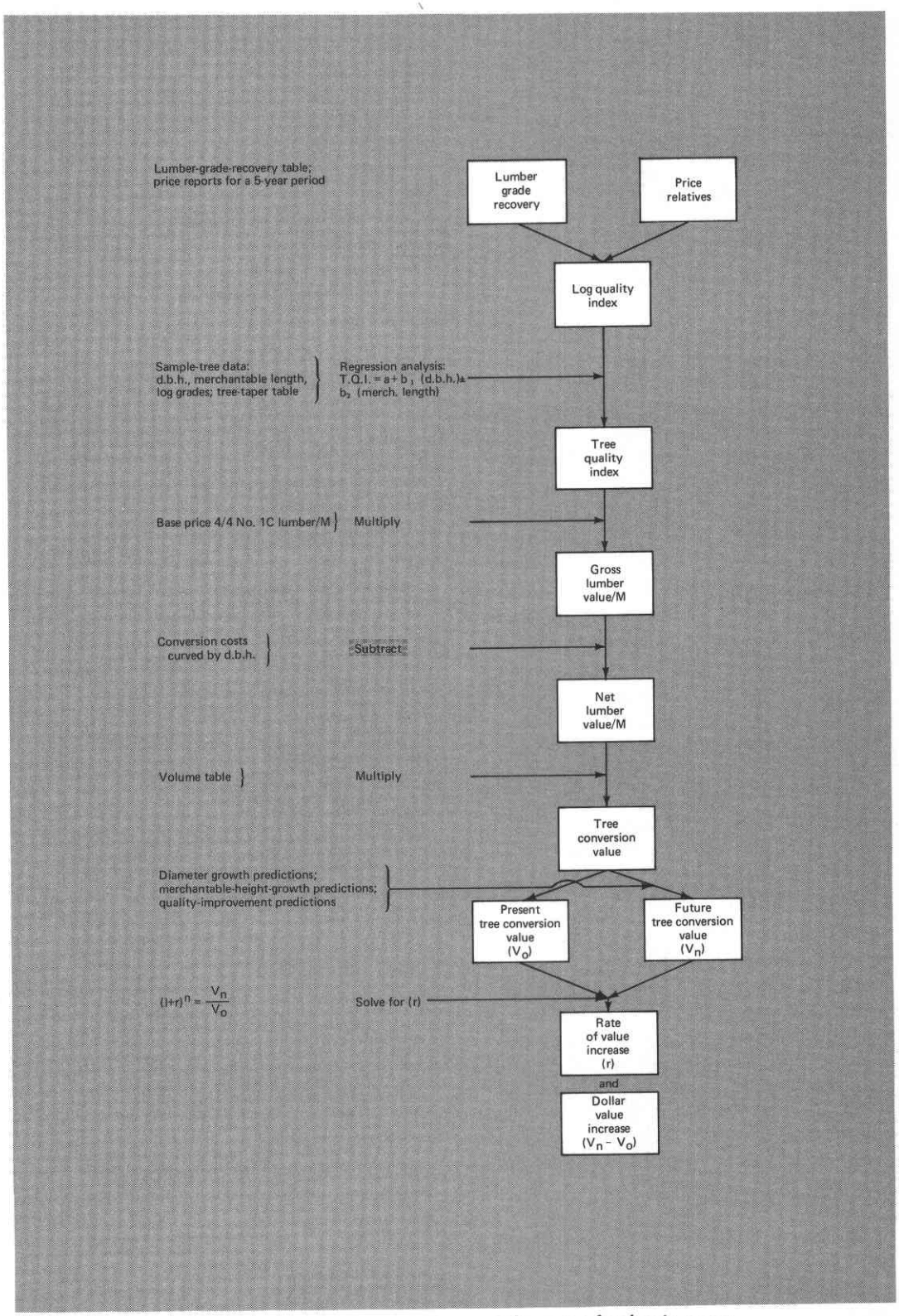


Figure 1.—Tree conversion value and the rate of value increase.

value would be $5.87. If, during the next 10 years, it grows 2 inches in diameter without increasing in sawlog height or improving in grade, its future value would be $11.37. The tree's V_n/V_o ratio would thus be $11.37/$5.87 or 1.938. Looking up 1.938 at 10 years in a compound-interest table, we find the tree's rate of value increase to be 6.8 percent.

On the surface, computing rate of value increase seems easy enough. The big part of the job is assembling tree-value data.

We employed the quality index (Q.I.) approach in developing tree values based on sawing logs into 4/4-inch lumber (fig. 1). Lumber-grade-recovery data and price relatives were used to develop log-quality index data, which were transformed into tree-quality index by regression analysis of sample-tree data, which provided information about the grade of the upper logs of the tree.

Gross lumber value was found by multiplying tree Q.I. by the existing price of 4/4 No. 1 Common lumber.

Net lumber value was determined by subtracting from the gross value all of the conversion costs involved in harvesting, transporting, and processing the tree into 4/4 lumber.

All of the values previously mentioned were on a 1,000-board-foot basis. Net lumber value when multiplied by the volume in the tree is the tree-conversion value or, more understandably, tree stumpage value.

The values obtained as above indicate a tree's net worth as 4/4 inch lumber, a consistent measure for a product common to most sawlog species. We can use the same set for both present and future values, if we are willing to assume that lumber prices and conversion costs will remain constant. And this has some merit, for its allows us to find the return that is directly attributable to a tree's development. We would be guessing at future lumber prices and conversion costs, anyhow.

All we need at this point is to estimate the changes in diameter, merchantable height, and log grade that are likely to occur during the growth period—10 years is a commonly used management period. We can also assume various combinations of changes in each, say by tree vigor class, and find the resulting future values. That is, we can determine the future value of a given tree if it does not increase in sawlog height or improve in log grade, if both height and grade increase, and if either height or grade increase during the 10-year period.

RESULTS

Basing our rate of value increase computations on all the possible future values for a single tree gives us a vast amount of detailed information (table 1). For convenience we can construct more generalized tables to show ranges in rates of value increase, reflecting differences in sawlog height and grade.

Table 2 shows the rates of value increase that we can expect, regionally, from 10 species common to the oak-hickory type. Keep in mind that rates of value increase are based on existing trees and their projected value increase over the next 10 years. Costs of growing the trees to sawtimber size are not considered. Nor are the fixed costs of taxes, protection, etc. These sunk and fixed costs will be the same regardless of the timber-cutting alternative the forest owner selects, or if he just chooses to let the trees grow.

Note the high portions of the ranges in rates. They are due largely to low-grade trees that have a low present value and thus produce a relatively high rate of value increase when considered in the ratio V_n/V_o. This is especially true in the estimates "due to growth and quality increase" for the smaller diameters, where we have grade 3 trees improving to grade 2. While those kinds of trees show high rates of return, they add little in the way of actual dollar value to a stand.

Note also that the rates decrease in the larger diameter classes. Again, this has to do with our V_n/V_o ratio. The larger trees usually have a big increase in dollar value, but their initial value is relatively large too. So the resulting V_n/V_o ratio gives a low rate of increase.

Another way to reduce our mass of detailed data is to develop financial maturity guides—tables showing the diameters at which trees cease to earn various levels of interest rates that a forest owner might deem acceptable (table 3). The diameters presented are based on value increases due to growth alone and must be adjusted upward where potential log-grade increase is involved. Dashes in the table show the vigor classes that fail to meet the indicated interest rates.

HOW RVI WORKS FOR INDIVIDUAL TREES

Before we can apply the rate of value increase or financial maturity concepts, we must know the rate of return we expect our timber to earn. That is, we must be aware of the forest owner's alternative rate of return—the interest rate that he expects for the use of his capital. This rate is peculiar to each owner's appraisal of his circumstances *(Duerr, Fedkiw, and Guttenberg 1956)*. And it is subject to change. The rate may be low, say 2 percent in cases where timber-growing is one of multiple use objectives. It may be the 4 percent foresters have seemingly adopted as classical. Or it may be 6 percent or higher, reflecting the current lower limits for alternate investments.

Alternative rate of return serves as a financial yardstick against which we can compare the rate of value increase for trees or stands. As such it gives us an economic basis for making cut-leave decisions. If a tree's rate of value increase is greater than our alternative rate of return, it is earning us more than we could get from selling the tree and investing its sale price. If the two rates are equal, we are equally well off if

Table 1.—*Determination of rate of value increase for 16-inch d.b.h. red oak, vigor 1, site index 80**

Present				Future						
D.b.h. inches) (1)	Butt-log grade (2)	Log height (feet) (3)	Tree value (dollars) (4)	D.b.h. inches) (5)	Butt-log grade (6)	Log height (feet) (7)	Tree value (dollars) (8)	Ratio V_n/V_o (9)	Rate of value increase (percent) (10)	Ten-year value increase (dollars) (11)
16	1	16	3.01	18.7	1	16	6.57	2.183	8.1	3.56
16	2	16	.90	18.7	2	16	2.83	3.144	12.1	1.93
16	2	16	.90	18.7	1	16	6.57	7.300	22.0	5.67
16	1	24	3.75	18.7	1	24	8.52	2.272	8.6	4.77
16	1	24	3.75	18.7	1	32	9.46	2.523	9.7	5.71
16	1	24	3.75	18.7	1	40	9.75	2.600	10.0	6.00
16	2	24	.96	18.7	2	24	3.55	3.698	14.0	2.59
16	2	24	.96	18.7	2	32	3.77	3.927	14.7	2.81
16	2	24	.96	18.7	2	40	3.66	3.813	14.3	2.70
16	2	24	.96	18.7	1	24	8.52	8.875	24.4	7.56
16	2	24	.96	18.7	1	32	9.46	9.854	25.7	8.50
16	2	24	.96	18.7	1	40	9.75	10.156	26.1	8.79
16	1	32	4.05	18.7	1	32	9.46	2.336	8.9	5.41
16	1	32	4.05	18.7	1	40	9.75	2.407	9.2	5.70
16	1	32	4.05	18.7	1	48	9.73	2.402	9.2	5.68
16	2	32	.77	18.7	2	32	3.77	4.896	17.2	3.00
16	2	32	.77	18.7	2	40	3.66	4.753	16.9	2.89
16	2	32	.77	18.7	2	48	3.34	4.338	15.8	2.57
16	2	32	.77	18.7	1	32	9.46	12.286	28.5	8.69
16	2	32	.77	18.7	1	40	9.75	12.662	28.9	8.98
16	2	32	.77	18.7	1	48	9.73	12.636	28.9	8.96
16	1	40	3.77	18.7	1	40	9.75	2.586	10.0	5.98
16	1	40	3.77	18.7	1	48	9.73	2.581	9.9	5.96
16	2	40	.35	18.7	2	40	3.66	10.457	26.4	3.31
16	2	40	.35	18.7	2	48	3.34	9.543	25.3	2.99
16	2	40	.35	18.7	1	40	9.75	27.857	39.5	9.40
16	2	40	.35	18.7	1	48	9.73	27.800	39.4	9.38

*No computations are shown for trees with negative present or future stumpage values as in the case of trees with a butt-log grade of 3 or local-use and and construction grade.

Table 2.—*Expected rate of value increase for tree species common to the oak-hickory type** (In percent)

D.b.h. (inches)	Due to growth only			Due to growth & quality increase		
	Vigor I	Vigor II	Vigor III	Vigor I	Vigor II	Vigor III
			RED OAK			
16	7-25	5-22	3-16	20-39	20-36	16-33
18	5-12	4- 9	2- 6	15-21	13-20	12-18
20	4- 8	3- 6	1- 4	12-16	11-15	9-13
22	3- 7	2- 4	1- 3	10-13	10-12	8-10
24	3- 7	1- 4	1- 2	9-12	8-10	7- 8
26	1- 5	1- 4	0- 2	8-10	7- 9	7- 8
28	1- 3	1- 3	0- 2	7- 9	7- 8	7- 8
30	1- 2	0- 2	0- 1	7- 8	7- 8	6- 7
			WHITE OAK			
16	4-24	3-21	2-18	15-38	13-36	12-35
18	3-21	2-19	2-14	13-31	12-29	11-28
20	2-11	2- 9	1- 7	8-15	7-14	6-13
22	2- 5	1- 5	1- 3	4-13	3-12	2-11
24	1- 3	1- 3	0- 2	2-12	2-11	2-11
26	1- 2	0- 2	0- 1	2-12	1-11	1-11
28	0- 2	0- 1	0- 1	2-12	1-11	1-11
30	0- 1	0- 1	0- 1	1-12	1-11	1-11
			BLACK OAK			
16	7-51	5-45	3-33	23-58	21-53	18-46
18	6-19	4-15	2-10	18-21	14-18	12-15
20	5-16	4-14	2- 9	12-20	9-16	7-15
22	4-13	3-11	2- 7	7-18	6-16	4-13
24	3-11	2-10	2- 3	5-16	3-15	2-12
26	3- 5	2- 4	1- 3	3-10	2- 9	2- 8
28	2- 5	2- 3	1- 2	—	—	—
30	2- 4	2- 3	1- 2	—	—	—
			CHESTNUT OAK			
16	3-10	2- 9	1- 6	19-24	18-23	17-21
18	2-14	2-12	1-10	14-23	13-24	12-22
20	2- 8	1- 7	1- 5	9-14	8-13	7-12
22	1- 5	1- 4	0- 3	6-10	5-10	5- 9
24	1- 2	0- 2	0- 1	5- 8	5- 8	4- 7
26	0- 2	0- 1	0- 1	4- 7	4- 7	3- 7
28	0- 1	0- 1	0- 1	3- 6	3- 6	3- 6
30	0- 1	0- 1	0- 1	3- 6	3- 6	2- 6
			HICKORY			
18	6-30	4-23	1-12	30-47	27-43	24-39
20	4-19	3-13	1- 6	19-31	16-28	14-24
22	4-13	2-10	1- 3	14-23	12-20	10-17
24	3- 7	1- 5	1- 2	11-15	10-14	8-11
26	2- 7	1- 5	0- 2	—	—	—
28	2- 4	1- 3	0- 1	—	—	—
30	2- 3	1- 2	0- 1	—	—	—
			YELLOW-POPLAR			
16	5-11	4- 8	2- 6	7-17	5-15	4-14
18	4- 8	3- 6	2- 5	6-13	5-11	3-10
20	3- 7	2- 5	1- 4	5-11	4-10	3- 8
22	3- 7	2- 5	1- 3	5-10	4- 9	3- 8
24	2- 4	1- 3	1- 3	4- 9	3- 8	3- 7
26	2- 3	1- 2	0- 2	4- 8	3- 7	3- 6
28	1- 2	1- 2	0- 1	—	—	—
30	1- 2	0- 2	0- 1	—	—	—
			ELM			
16	6-29	4-23	2-14	16-37	13-33	10-27
18	5-18	3-15	2- 9	11-24	9-21	8-17
20	4-15	3-12	1- 7	9-19	7-17	5-13
22	3-12	2-11	1- 6	7-16	5-15	3-11
24	3-10	2- 9	1- 5	5-14	4-13	3- 9
26	2- 4	1- 3	0- 2	4- 8	3- 7	2- 6
28	2- 4	1- 3	0- 2	—	—	—
30	2- 3	1- 2	0- 1	—	—	—

Table 2.—*Continued*

D.b.h. (inches)	Due to growth only			Due to growth & quality increase		
	Vigor I	Vigor II	Vigor III	Vigor I	Vigor II	Vigor III
			SUGAR MAPLE			
16	4-12	3- 9	2- 7	9-20	8-18	7-15
18	3- 8	2- 7	2- 5	6-15	7-13	5-12
20	3- 6	2- 5	1- 4	6-13	5-12	4-11
22	2- 5	1- 4	1- 3	5-11	4-10	4-10
24	1- 4	1- 3	1- 3	5- 9	4- 8	3- 8
26	1- 3	1- 2	0- 2	4- 7	3- 7	3- 6
28	1- 2	0- 2	0- 1	—	—	—
30	0- 2	0- 1	0- 1	—	—	—
			RED MAPLE			
16	4-12	3- 9	2- 7	6-16	5-13	4-12
18	4-11	3- 8	2- 6	5-14	4-11	3-10
20	3-11	3- 7	1- 5	4-13	4-10	2- 8
22	3- 8	2- 6	1- 4	3-10	3- 8	2- 6
24	2- 7	2- 4	0- 3	3- 8	2- 6	1- 4
26	2- 5	1- 4	0- 2	2- 6	2- 5	0- 3
28	2- 3	1- 3	0- 1	—	—	—
30	1- 2	1- 2	0- 1	—	—	—
			WHITE ASH			
16	4-39	3-36	2-33	7-58	6-54	4-52
18	4-23	3-15	2-14	7-32	4-27	3-26
20	3-18	2-12	1-10	5-26	4-22	3-21
22	3-13	2- 8	1- 7	4-18	3-15	2-14
24	2-10	2- 6	1- 5	3-14	3-13	2-13
26	2- 8	1- 5	1- 4	3-13	2-12	2-12
28	2- 3	1- 2	1- 2	—	—	—
30	2- 3	1- 2	1- 2	—	—	—

*Based on 4/4 factory-grade lumber recovery. These rates can have a variation of 2 to 4 percent due to differences in location, volume estimates, and quality estimates.

we sell the tree or keep it. But, if the tree's rate of value increase is less than our alternative rate, we would be better off, financially, to sell the tree and invest its value at our higher alternative rate.

Let's say that our alternative rate of return is 4 percent. Recall the 20-inch red oak we used in an earlier example (tree A). As it grows during the 10 year period, the tree will increase in value $5.50, or at a compound rate of 6.8 percent. If we sell the tree and invest its present value ($5.87) at our 4-percent alternative rate, we would expect to earn only $2.64. Thus we would be $2.86 ahead by letting the tree grow.

Suppose we had another red oak (tree B) similar to the first one, but about 2 inches larger:

	Tree A	*Tree B*
D.b.h. (inches)	20	22
Vigor class	I	I
Log grade	2	2
No. logs	3	3
Present value (V_o)	$ 5.87	$11.08
Future value (V_n)	$11.37	$17.26
Value increase	$ 5.50	$ 6.18
Rate of value increase	6.8%	4.5%

Note that tree B is increasing in value at a lower rate than tree A. But as long as we keep our 4-percent alternative rate, we would be wise to let tree B grow, too, since it is returning more than 4 percent.

But suppose our alternative rate of return is 6 percent. In this case tree A is still a good bet to leave. Not so with tree B. Let's look at the cutting options we have, cutting either tree, both trees, or neither one:

	Options			
	(1) Cut Tree A	*(2) Cut Tree B*	*(3) Cut both*	*(4) Cut neither*
Value of tree cut, invested at 6 percent compound, earns in 10 years:	$ 4.64	$ 8.75	$13.39	—
Value increase of tree left:				
Tree A	—	5.50	—	5.50
Tree B	6.18	—	—	6.18
Total value added in 10 years	$10.82	$14.25	$13.39	$11.68
Rate of value increase	5.1%	6.3%	6.0%	5.4%

Table 3.—*Financial-maturity diameters based on value increase determined by growth alone*

Vigor class	Alternative rate of return		
	2 percent	4 percent	6 percent
	RED OAK		
I	25	21	18
II	23	19	16
III	19	16	—
	WHITE OAK		
I	23	17	15
II	21	15	14
III	19	14	—
	BLACK OAK		
I	30+	23	19
II	30	21	16
III	25	16	15
	CHESTNUT OAK		
I	21	16	15
II	19	15	—
III	16	15	—
	HICKORY		
I	30+	22	18
II	23	19	—
III	17	—	—
	YELLOW-POPLAR		
I	27	20	15
II	23	17	13
III	19	13	12
	ELM		
I	30+	22	17
II	25	17	15
III	19	15	—
	SUGAR MAPLE		
I	24	17	15
II	22	16	—
III	19	13	—
	RED MAPLE		
I	29	19	14
II	26	16	13
III	19	14	12
	WHITE ASH		
I	30+	19	15
II	25	16	13
III	20	13	—

The first option is our poorest one. We lose by cutting tree A and investing its value at 6 percent. Allowed to grow it would earn 6.8 percent. We lose by not cutting tree B. It is returning only 4.5 percent in the woods, and its value could be earning our alternative 6 percent elsewhere.

The second option gives the highest possible return. We take advantage of tree A's earning power by letting it grow. We also take advantage of our alternative rate of return by investing tree B's value at the higher 6-percent rate instead of letting it grow at the lower 4.5-percent rate.

The third option satisfies our 6-percent requirement. We can obviously get the rate of return we want by cutting both trees and investing their value at that rate. In doing so we sacrifice some of tree A's earning power while effectively using tree B's cash value at our higher alternative rate.

The fourth option shows the net return from letting both trees grow. We get an acceptable return from tree A, but not from tree B. As a result, their combined value increase is not enough to give us the 6-percent return we want.

SOME ECONOMIC PRINCIPLES

The above examples point out some principles that are important in applying the rate of value increase concept.

1. The financial maturity idea.—When a tree first reaches sawtimber size, it usually has a negative or low stumpage value, but it increases in value rapidly. Then its rate of value increase gradually diminishes until it falls below the forest owner's alternative rate of return. The diameter at which this occurs is the point of financial maturity.

The two trees in our example illustrate the financial maturity idea. At 20 inches tree A has a rate of value increase that exceeds the net return possible from selling the tree and using its cash value elsewhere. At 22 inches tree B—similar to tree A, but larger—no longer pays its own way. Expecting a 6-percent return in our invested capital, we would consider tree B financially mature.

2. *The let-it-grow option.*—The forest owner may set an objective of meeting his alternative rate of return. To judge his success as a timber grower, he needs to know whether or not his trees are earning him his required rate. He can find out by looking at the rates of return he can expect if he lets them grow. Option 4, his let-it-grow option, illustrates this.

3. *The principle of maximum net return.*—The forest owner, like any other businessman, would enjoy earning the highest net return from his invested capital. To achieve the maximum net return from his timber growth, he should maintain in his stands the greatest possible value in trees that are growing at or above his alternative rate, and liquidate those trees that are growing below (or never will meet) that rate.

HOW RVI WORKS FOR STANDS OF TREES

We can place a value on a stand by summing the values of the trees that make up the stand, both now and in the future. Again, the big job is determining tree values. But we already have them from our tree rate computations—an added benefit from our work. Thus, we can apply tree values to our present stand tables, grow the trees for 10 years, and apply values to the resulting future stand tables. The rate of value increase for the stand would then be based on the ratio V_n/V_o.

Unfortunately, we will have to limit ourselves to sawtimber stands or to the sawtimber portions of stands, since we have not developed RVI data for other products. When data are developed for other products or product mixes, we can enlarge the scope of our stand valuations to include most (if not all) of the trees in a stand. And the economic principles behind the rate of value increase concept would still apply—the same principles that we discussed for individual trees.

Take, for example, a typical acre of oak-hickory sawtimber in southeastern Ohio. Its basal area is made up as follows:

Sawtimber trees	63 square feet
Poletimber trees	24 square feet
Cull trees	9 square feet
Total	96 square feet

After applying values to the sawtimber trees in the stand, we can break them down further into:

Trees with positive value	25.1 square feet
Trees with negative value:	
11 to 16 inches d.b.h.	32.8 square feet
16 inches + d.b.h.	5.1 square feet
Total	63.0 square feet

The trees with positive values are as follows:

D.b.h. (inches)	*Vigor*	*Basal area (sq. ft.)*	*Log grade*	*Present value ($)*	*Future value ($)*	*10-year value increase ($)*	*Rate of value increase (%)*
16	1	1.2	1	3.75	7.90	4.15	7.7
	1	1.3	1	3.75	8.72	4.97	8.8
	1	1.3	1	4.05	8.72	4.67	8.0
	1	1.3	1	4.05	8.95	4.90	8.2
	1	1.3	1	4.05	8.85	4.80	8.1
	2	1.4	2	.35	2.33	1.98	21.0
	2	1.4	1	3.75	6.60	2.85	5.8
	2	1.4	2	.35	2.33	1.98	21.0
	3	1.5	1	3.75	5.43	1.68	3.8
	3	1.5	1	4.05	5.89	1.84	3.8
18	2	1.6	1	7.92	12.36	4.44	4.6
	2	1.7	1	7.92	12.58	4.66	4.7
	2	1.8	2	2.61	5.18	2.57	7.1
22	1	2.5	1	21.32	30.40	9.08	3.6
26	2	3.9	2	20.10	23.60	3.50	1.6
Total		25.1		91.77	149.84	58.07	5.0

Note the detailed value data in the four right-hand columns. We can derive such data only if we know each tree's butt-log grade. Unfortunately, quality information is often neglected in management inventory work.

Note, too, the variation in individual tree rates from 1.6 to 21.0 percent and their overall 5.0 percent rate of value increase. The acceptability of these rates depends on the owner's alternative return requirements and on whether he expects the sawtimber portion of the stand or each sawtimber tree to meet that requirement. This portion of the stand obviously meets a 2- or 4-percent requirement, but not a 6-percent requirement. If the owner wanted his stand to earn him 2 or 4 percent he might well be content to let the trees grow.

But if he wanted a 2 or 4 percent return from each tree, we would have to cut those growing below those rates and invest their value at the higher alternative rate. The same would apply for a 6-percent return expectation, as far as individual trees are concerned. If the owner wanted 6 percent from his stand, the sawtimber portion would be, in a sense, financially mature. But unlike individual trees, we would not have to cut the entire stand. We can meet his requirement by cutting only the poor earners and investing their cash value at 6 percent while leaving the good earners grow at better than 6 percent.

Actually, when we expect each tree in a stand to earn at least our acceptable rate of return—either through growth or through liquidation and reinvestment—we are insisting on obtaining a maximum net return on our capital investment. If we pursued this principle in our example, we would get the following results:

The basal area removed in each case is the total basal area in trees that do not meet our alternative rate of return. The reinvested cash value of these financially mature trees, plus the value increase of the trees left to grow, equals the stand's future value (V_n).

In each case we would raise the net return above what we could expect by letting all the trees grow—our let-it-grow option. For each of the requirement levels the value increase represents the maximum net return possible.

Let's say now that, in addition to our investment requirements, we had a silvicultural requirement to reduce the overall stand basal area to 70 square feet. How would this affect our cut-leave decisions? First, we would probably kill our 9 feet of basal area in cull trees. These will never add value to our stand. Then we would take out the 5 feet of negatively valued trees over 16 inches d.b.h. These are grade 3 or tie-and-timber quality trees that are unlikely to add any value to the stand. This would leave us 81 square feet of basal area. If we now remove the financially mature sawtimber trees, the basal areas would be, in square feet:

	Alternative return		
	2%	*4%*	*6%*
Remaining	81	81	81
Remove	3.9	9.4	14.1
Residual	76.1	71.6	66.9

Our residual basal area at the 2- and 4-percent interest levels would still exceed our 70-square-foot requirement. We can still remove about 6 more feet with our 2-percent requirement and about 2 square feet with our 4-percent requirement. These trees might be sawtimber trees under 16 inches d.b.h. that show no promise of im-

Requirement (Pct.)	*Remove BA/A (Sq. ft.)*	V_o	V_n	*Value increase*	*RVI (Pct.)*
2	3.9	91.77	150.74	$58.97	5.1
4	9.4	91.77	157.36	$65.59	5.5
6	14.1	91.77	176.15	$84.38	6.7

proving in log grade, or they might be poletimber trees of low vigor. But with our 6-percent requirement we would dip under our 70-square-foot basal area requirement. We would thus have to decide on which of the two objectives we wanted to meet.

In either case we could determine the cost involved. Chances are we would be likely to assume that 67 square feet is close enough to 70. But what if we needed to earn an 8-percent return on our capital investment? Again, we would have a choice to make, weighing long range silvicultural principles against shorter range economic ones.

The final decision, of course, would rest on the forest owner's policies. However, with our rate of value increase information, we would be able to advise him as to the business aspects involved—the cost of following a silvicultural recommendation or the return that could result from rejecting it. In either case the owner would be in a better position to decide on which course to follow.

CONCLUSIONS

We have introduced a logical method for evaluating trees, projecting that valuation over a 10-year period, and determining the rate of value increase. This method is useful not only for evaluating an individual tree, but also for evaluating future diameter growth, increase in merchantable height, and improvement in tree quality. Further, it is complementary to forest-management techniques whether it be selection or even-aged management, in that it places a dollar valuation on the product as it develops to maturity. Its applicability to stand valuation has been demonstrated, and the need for information about quality of the product is duly noted.

But, most noteworthy of all, it is a calculable measure of the financial maturity of the end product, and we no longer need to accept the tacit reckoning of when to cut. The rate of value increase is the measure that, combined with basal-area requirements of silviculturists, will also provide a more adequate base from which to determine what to cut.

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OAK MANAGEMENT FOR WOOD PRODUCTS

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ABSTRACT. A method is presented for analyzing oak management alternatives through comparisons of the present value of the net cash flow produced. Even-aged management without age-class regulation returned $72.60 of present value over a 40-year period. In the next 40 years the only expenses reduce the present value to $72.43. To regulate this stand into a forest with an equal number of acres in each age class, the present value is estimated to be $71.08, for a regulation cost of $1.35 per acre. The average acre, selectively cut to create an all-aged stand, returns a present value of $63.17. This is a cost per acre of $7.91 for this type of management compared to the regulated even-aged forest.

AS A WOODLAND MANAGER responsible for growing timber products for a pulpmill, sawmills, and a veneer mill—while maximizing a return on the forest investment—I am concerned with the analysis of different management alternatives. So I will present a method of comparing different courses of action to maximize the return on an oak forest investment.

The first step in the analysis is a field inventory showing diameter distribution, stand age and number of stems, and volume and basal area per acre. This acre supports an oak stand that is typical in form of a large area of the Appalachians. It contains trees from 5 inches d.bh. to 24 inches d.b.h., with an average d.b.h. of 9.7 inches and a mode d.b.h. of 8 inches. It contains 19.9 cords, 1,355 board feet Doyle, a basal area of 110.1 square feet, is 60 years old, and has never been managed.

The value of this stand is computed at $1.50 per cord and at a variable board-foot price depending on the lumber return and manufacturing costs from $22.00 per M board feet to $54.14 per M board feet, with a resulting total wood volume value of $72.18. The bare land value is assumed at $5. The total value is $77.18 for the typical acre.

This value becomes a base to work from. We can, if we wish, liquidate our investment now or continue to manage in the expectation that it will return an acceptable rate of interest on the investment. An acceptable interest return for this would be 9 percent compound interest after taxes.

The next step is to simulate a hypothetical situation where the present stand can grow, and where it can be managed so the resulting future forest-product yields can be calculated with some degree of accuracy. The hypothetical stand is growing at the rate of 15 rings per inch for stems 6 to 8 inches d.b.h., 10 rings per inch for stems 10 to 12 inches and 8 rings per inch for stems 14 inches and larger. After 15 years of management, it is assumed that stems of all

diameter classes grow at 10 rings per inch. This stand is considered to be on a better-than-average site.

The next step is to compute the present value of future income created by the management method under consideration. To illustrate this procedure, two management alternatives will be considered. Alternative No. 1 will program the hypothetical acre to maximize profit through intensive even-aged management. Alternative No. 2 will maximize profit through intensive all-aged management.

ALTERNATIVE 1: MAXIMIZED PROFIT BY INTENSIVE EVEN-AGED MANAGEMENT

To maximize profit, it is important to maximize early cash flow (after tax net profit plus depletion), taking care not to destroy a future potential. Cash flow, as an economic concept to determine return on investment, has created controversy among economists for some time. The fact that it includes depletion and depreciation as income, when to accountants they are considered costs, is at the root of the conflict. I feel that cash flow is a sound logical concept for a forest land investment in that we are dealing with a factor that produces a product forever without repair or additional capital expenditures. Unlike a sawmill, which must be overhauled or replaced periodically, the forest factory can be productive forever, can return the original investment, and at the same time can hold more volume than when it was purchased.

The first cut will be made to remove the larger sawlog trees, which are, for the most part, defective holdovers. In addition, it is important to remove, as pulpwood or bolts, those stems that will never make sawlogs This includes defective stems, low-quality trees lacking the ability to reach sawlog grade 2 at 14 inches d.b.h., and those stems that because of crowding will need to be removed to allow the better trees to develop. In this example, a total of 95 trees are all that will reach sawlog size under even-aged management.

Our first cutting removes 49 percent of the sawlog volume, 37 percent of the pulp volume, and 46 percent of the value (table 1). The objective is to group the diameters

Table 1.—*Typical first thinning in a previously unmanaged stand under the maximated profit alternative*

D.b.h. (inches)	No. stems	Board feet	No. stems	Cords	Basal area
			CUT		
6	—	—	20.0	0.6	3.9
8	—	—	40.8	2.9	14.0
10	—	—	7.1	1.0	3.9
12	—	—	3.0	0.6	2.4
14	1.9	99	6.7	1.8	9.2
16	3.2	187	1.0	.3	5.9
18	1.2	132	.4	.2	2.8
20	.5	85	—	—	1.1
22	.5	101	—	—	1.3
24	.2	60	—	—	.6
Total	7.5	664	79.0	7.4	45.1
			LEAVE		
6	—	—	36.0	1.2	7.0
8	—	—	20.0	1.4	7.0
10	—	—	42.0	5.9	22.8
12	—	—	20.0	4.0	15.6
14	7.0	373	—	—	7.5
16	3.0	263	—	—	4.2
18	.5	55	—	—	.9
Total	10.5	691	118.0	12.5	65.0

as tightly as practical with approximately 60 trees per acre of the best and biggest trees. I have chosen those trees in the 8 to 12-inch classes for my final clearcut while removing as many 6-inch trees as is practical and the mature and defective trees. If this initial cut results in a remaining basal area below that that will create maximum growth, it is not important. Under utilization of the site is only temporary, and the growth lost is pulpwood which, in this stand, can only be grown as a byproduct. Pulpwood growth seldom gives an acceptable return on investment, although many trees return their maximum return in this form.

Branching may be a problem when a stand is cut this drastically. I feel that this is a real consideration, and an area where more research should be done. My somewhat limited experience in this kind of cutting has convinced me that a residual basal area as described above will create at least some branching, but mostly confined to suppressed trees and upper crowns of intermediates.

In fifteen years, the stand will be thinned again, returning $76.80 from 1,773 board feet and 3.6 cords. Dollar values are at today's prices. In 30 years, another thinning returns $111.20. This stand is clearcut in 40 years, returning $312.10.

The question is: How good an investment has this been? Assume property taxes at $0.30 per year, overhead at $1 per year, and timber depletion as an additional expense of $3 per cord equivalent. For this computation, board-foot volume is converted to cords at the rate of 3 cords per 1,000. Taxes are computed on the assumption that the business has ordinary income; that is, income other than that receiving a capital-gains treatment. The expenses are used to offset this ordinary income, creating a tax savings to the business equal to 50 percent of the expense. It is also assumed that the timber values sold qualify for capital-gains treatment. Future cash flows are discounted at 9 percent.

This total computaton shows a combined discounted cash flow of $72.64 (table 2). Since the theoretical acre cost $77.18, it might first appear that the investment did not return 9 percent, and we should sell the land now and invest our money elsewhere. This is not necessarily the case, however, because increasing stumpage and land values were not a part of the computation. I feel that the effects of inflation or changing supply and demand are quite speculative and are not needed in a comparative analysis. If the purpose of analysis is to justify a purchase, future values and costs must be considered.

Observations of this management method are made easily by watching the simulation model develop. The management shown did not create a sustained yield in that sawlogs

Table 2.—*Computation of the after-tax present values of future cash flow-maximum profit alternative*

Item	Years						Residual value
	0	10	15	20	30	40	
Pulpwood income	$11.10	—	$ 5.40	—	—	—	—
Sawlogs income	24.84	—	71.40	—	$111.20	$312.10	—
Total	35.94	—	76.80	—	111.20	312.10	—
Property tax & overhead	—	—	19.50	—	19.50	13.00	—
Post-tax expense	—	—	9.75	—	9.75	6.50	—
Depletion	28.20	—	26.70	—	16.28	—	—
Income less depletion	7.74	—	50.10	—	94.92	312.10	—
Post-tax income	5.80	—	37.58	—	71.19	234.08	—
Cash flow	34.00	—	54.53	—	77.72	227.58	$1.16
Discounted cash flow	34.00	—	23.04	—	6.96	8.60	.04
Total discounted cash flow	—	—	72.60	—	—	—	—
Bare land value	—	—	.04	—	—	—	—
Total	—	—	$72.64	—	—	—	—

are produced beginning at age 60 and increase in volume to a very heavy cut at maturity. Pulpwood is produced at ages 40 through 70 as a byproduct of sawlog production. Because a large percentage of the oak type being considered is approximately 60 years of age, to accomplish sustained yield in the forest an investment in age-class regulation will be necessary.

A calculation of present value, similar to the above but not clearcutting until 90 years from now, results in $69.52. The cost of regulation for a stand made up of our simulated acre would be somewhere between the difference of our maximized profit stand and clearcutting in 90 years; assuming that acre regulation is to take place with mature timber, rather than clearcuts in immature stands. The present value of a regulated even-aged forest is probably close to the average of the two simulations, or $71.08.

ALTERNATIVE 2: ALL-AGED STAND CONVERSION

This analysis is not based on observations or measurements of actual stands, because I have yet to see an all-aged stand. My hypothetical stand is the same as case study No. 1 and is cut to maximize profit while creating a new age class every 10 years. The new age class covers 1/9 acre (90 year rotation) and requires the allocation of 12 square feet of basal area. The stand simulation thins 757 board feet and 7.4 cords with a value of $38.71. This is a heavier cut than our first alternative because of the need to reduce the basal area sufficiently to create a new stand.

The acre is cut according to the individual selection system for 80 years, in which time the original stand is completely removed through nine cuttings designed to create nine age classes.

I question whether it is possible under any practical management to create more than a two-storied stand. I base this on the feeling that to create surviving reproduction in our stand, the basal area must be reduced to 40 to 50 square feet and not be allowed to increase above 60 to 70 square feet before cutting. An initial cut this heavy would not leave enough stems to make partial cuttings economic over the regulatory period. Also, the quality of trees grown in this way would be very poor. In short, the all-aged acre probably does not exist except as a mental concept, and individual selection belongs as an intermediate partial cutting tool and not as a management philosophy.

The simulation was programmed to attempt the creation of an all-aged forest in a way that has a practical field application. The present value of the acre is $63.24, which includes the value of the stand remaining at the end of the regulatory period. Sawlogs were produced in fairly equal amounts every 10 years on what could be considered a sustained-yield basis. Pulpwood was produced in the first, seventh, and ninth cuttings, producing less total pulpwood than any system, and certainly not on a sustained-yield basis. The problem with pulpwood appeared immediately in the program when low production of only a cord or two per cutting was considered to be uneconomical to harvest. It was removed in partial cuttings only when its volume reached 4 cords per acre which, along with the sawlog component, could then be produced economically.

All-aged management will create a steady flow of logs and an intermittent pulpwood cut. Compared to even-aged management you can expect higher logging costs, higher management expense, and less usable wood growth.

MANAGEMENT ALTERNATIVE COMPARISON

Forest investments involve considerations of payback times, dilution of earnings and, of course, return on investment. In order to show these factors in a form that can be used to compare alternatives, a *present value index* is computed, using a 9 percent return as the point of comparison (table 3). For this example land value is assumed to increase in value by 9 percent to eliminate it as a factor in the comparison.

The stand on the sample acre has been grown in an assumed economy without inflation or increases in sawlog or pulpwood values. This has been done to avoid confusion or distortions that might have existed

under an assumed drastic change in sawlog values, as an example. It is probable that a decreasing price for logs would result in a shorter rotation and a poorer profit picture while a sharply increasing future price would have the opposite effect. Table 2 is designed to allow future unit value changes along with predicted changes in costs. Table 3 is designed to include the future land values along with its growing stock.

The culmination of all the economic factors shows "all-aged conversion" as the system that maximizes profit for the first 10 years (fig. 1). At 15 years "maximized income" and "even-aged acre regulation" take the lead with "maximized income" showing its economic dominance after 30 years.

It can be seen that a company accustomed to a 9-percent return will suffer a dilution of earnings for 40 years. It takes 15 years to pay back the original investment under "maximized income" while "all-aged conversion" returns all but $1.15 in 10 years.

The sample acre as an investment does not look good compared with the large variety of other uses money can be put to. Our jobs, as foresters, is to improve the picture through the principles of multiple use and a more concerned role in the development and sales of forest-based products. We need to predict increasing unit prices for the future and incomes from sources other than wood.

FUTURE TIMBERLAND POTENTIALS

Management in today's complex world requires a broader understanding of the

Table 3.—*Economic comparisons of management alternatives*

Item	Years				
	0	15	30	40	80
Maximum income:					
Original investment	$77.18	$77.18	$77.18	$77.18	$77.18
Less present value timber cash flow	34.00	57.04	64.00	72.60	72.43
Net land investment	43.18	20.14	13.18	4.58	4.75
Less present value of land	5.00	5.00	5.00	5.00	5.00
Net present value cash in (out)	(38.18)	(15.14)	(8.18)	.42	.25
Present value index*	.51	.80	.89	1.01	1.00
	Years				
	0	15	30	40 • • •	90
Even-aged acre regulation:					
Original investment	$77.18	$77.18	$77.18	$77.18	$77.18
Less present value timber cash flow	34.00	57.04	64.00	66.96	69.52
Net land investment	43.18	20.14	13.18	10.22	7.66
Less present value of land	5.00	5.00	5.00	5.00	5.00
Net present value cash in (out)	(38.18)	(15.14)	(8.18)	(5.22)	(2.66)
Present value index*	.51	.80	.89	.93	.96
	Years				
	0	10	20	30 • • •	80
All-aged conversion:					
Original investment	$77.18	$77.18	$77.18	$77.18	$77.18
Less present value timber cash flow	36.31	53.09	58.33	61.13	63.17
Net land investment	40.87	24.09	18.65	16.05	14.01
Less present value of land	5.00	5.00	5.00	5.00	5.00
Net present value cash in (out)	(35.87)	(19.09)	(13.65)	(11.05)	(9.01)
Present value index*	.54	.75	.82	.86	.88

* Present value index = $\frac{\text{Present value timber cash flow \& present value of land}}{\text{Original investment}}$

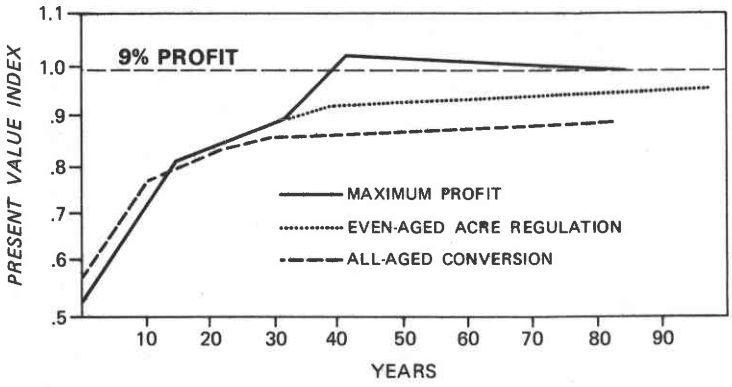


Figure 1.—A graphic comparison of the present value index created by management alternatives versus a 9-percent expected return on investment.

world around us than ever before. We are being asked to predict the future and, perhaps most important of all, to justify the existence of forest land as an investment with a fair return of wood products as a return on that investment.

The last 20 years has shown a phenomenal increase in the value of timberland (fig. 2). If this past performance continues into the future, profits from a forestry investment would seem to be assured, no matter how poorly we manage. However, maximized profits are realized by understanding this increase.

There are three major factors to be considered; bare-land value increase due to recreation demand, increase in stumpage values, and the movement of low-value pulpwood-size trees into the much higher value sawlog class. In the past 20 years, pulpwood stumpage values have not increased significantly, while sawlog values have increased 510 percent. The growth of pulpwood trees into sawlog trees has re-

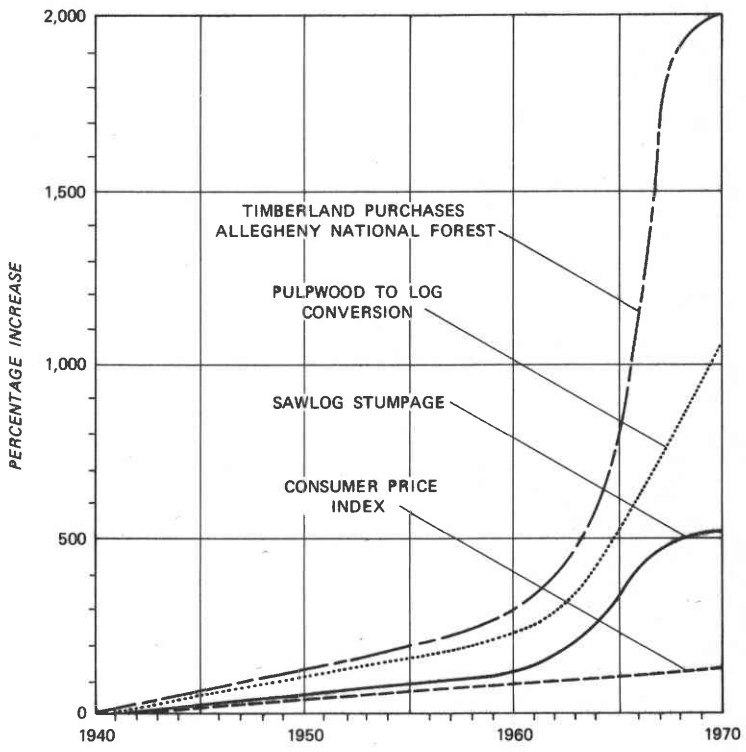


Figure 2.—Consumer price index compared with timberland appreciation.

sulted in 1,000 percent increase in value, leaving a comparatively meager 364 percent growth attributable to bare land values. I believe that the bare-land increase is deceiving in that recent years have introduced a buyer of timberland willing to pay about the same for a fully stocked acre as he will for a cut-over acre. So my figures are significant only in sales to forest-product-oriented buyers.

I feel that the stumpage-value increases will not be repeated in the next 20 years but will increase with lumber-value increases or at about the same rate as the cost of living. As forest managers, there isn't much we can do about this except to improve our marketing.

A manager's best opportunity to create maximum timber profits will be his management of potential sawlog trees. The sample acre, under maximized profit, shows increasing movement into sawlog sizes with value increases of this type ending in about 25 years.

The near future appears very favorable for timberland values, but they will not increase as much as would be indicated from a projection of the last 20 years. Also, much of the profit will be tied up in bare land and growing stock, which means that the investment will have to be liquidated to realize the profit. This is not always a feasible alternative for a wood-using industry.

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MULTIPLE-USE MANAGEMENT OF UPLAND HARDWOOD FORESTS

by FREDERICK A. DORRELL, *Forest Supervisor, Monongahela National Forest, Elkins, W. Va.*

ABSTRACT. In recent years the National Forests have experienced much controversy over multiple-use management. Because of this, the Forest Service is examining ways to improve the multiple-use planning process. One of the new approaches involves a special plan for eight National Forests in the South and Central Appalachian Mountains, in which planning is done by interdisciplinary teams, and the public is significantly involved in the planning process. A guide has been prepared, and planning is starting for the smaller units within the area. In the early stages, this new method of multiple-use planning is meeting with strong public support.

IN RECENT YEARS the National Forests have been the subject of much controversy, usually involving some public group that disagrees with the Forest Service's management practices in a particular area. The public group usually has a special interest that they feel is not being satisfied by the Forest Service multiple-use management plans. The disagreements become quite intense, and some end up in court.

Because of these conflicts, the Forest Service is examining ways to improve its multiple-use planning process. Different planning organizations and methods are being explored and tested in various parts of the country. A new approach to multiple-use planning is being developed for a group of National Forests in the South and Central Appalachian Mountains.

The part of the Appalachians involved in this special planning extends from northern West Virginia to northern Georgia, including parts of Virginia, Tennessee, North Carolina, and South Carolina. The National Forests within it are the Monongahela, George Washington, Jefferson, Pisgah, Nantahala, Cherokee, Chattahoochee, and part of the Sumter.

This area is a natural and logical planning unit. It contains similar terrain, climate, and forest conditions throughout. Rural development considerations are important. Local economic and social needs that depend on forest commodities frequently conflict with the recreation amenities demanded by surrounding urban population centers. Traditional resource uses such as timber harvesting are opposed by demands for wilderness preservation. The National Forest land managers are beset with many problems trying to balance the uses of the public lands. They have a tremendous challenge to develop better land-use plans and make them more acceptable to more of the public.

Before discussing the new approach, I will comment briefly on the present multiple-use planning system. Plans are made at

the Ranger District level in accordance with guides developed at the Regional level. The Regional guides are very broad, as they cover a large area containing many different situations. The Ranger District plans are more specific and employ the zoning concept. The District is zoned according to the resource situations and uses. Objectives for each zone are established, and decisions are made to coordinate the different management activities in the zones. Some major problems in this approach are:

- Since planning expertise and special talents are most often located at higher levels of the Forest Service than the Ranger Districts, they do not play a big enough role in multiple-use planning.
- The higher level experts do prepare functional plans for management of single resources such as timber and recreation. Instead of being governed and directed by multiple-use plans, these functional plans sometimes have more force than the multiple-use plans and can be in conflict with each other. The tail can wag the dog.
- The public is not involved in the planning process.

The new approach is designed to overcome these major problems. It has two main characteristics. (1) Planning is done by interdisciplinary teams. (2) There is significant public involvement.

The New Approach

This new approach for multiple-use planning in the South and Central Appalachian National Forests was activated in August 1970 by the Regional Foresters and Forest Supervisors of the Forests involved. A special interdisciplinary team was formed to spearhead the planning. The first step was to involve the public through a series of listening sessions.

The planning team traveled throughout the area and conducted open meetings at which the public was invited to present their ideas and comment on the new planning system. The team also consulted with many knowledgeable and concerned groups such as the Appalachian Regional Commission, local governments, universities, and conservation organizations. Questionnaires were distributed to Forest Service employees, and discussion meetings were held. Based on all this, the planning team developed a planning system and a draft for a proposed planning guide.

The various public elements were again involved in reviewing the proposed guide. Another round of listening sessions was conducted, and comments were solicited from interested parties. A thorough review was made by all of the involved Forests. The team redrafted the guide. After a final review, the guide was issued in June 1971. The final product is marked not only by Forest Service expertise, but, more importantly, by tremendous public involvement. It is designed for application to the specific Appalachian area involved. It contains objectives for this special planning area and establishes guidelines for carrying them out in a consistent and uniform way.

The main feature of the planning system is the unit plan. The total area will be divided into logical planning units. They will most frequently be watersheds, but will not be required to adhere to Ranger District, Forest, State or any other artificial or political boundaries. The aim is to have a natural planning unit subject to intensive planning within, and consideration of the needs of the whole of which it is a part.

Gains Public Support

After issuance of the guide, the actual unit planning was begun in the summer of 1971. Interdisciplinary teams are being formed on each involved National Forest. They include geologists, wildlife biologists, soil scientists, landscape architects, foresters, and other professionals. All levels and units of the Forest Service may be asked to participate. Cooperating agencies will be called on for participation. The teams will be charged with developing unit plans in accordance with the guide. The main steps will be as follows:

1. Gather basic data and inventory resources of the unit.
2. Conduct listening sessions and tours to gain public understanding and participation.

3. Analyze the data and public input and draft a proposed unit plan.
4. Conduct another round of public review and comment.
5. Make a final draft of the unit plan for review and approval by the Forest Supervisor.
6. The Forest Supervisor will distribute the unit plan within the organization and to the public.

These are the main features of unit planning. Also built into the system are other features such as computerizing the data, plan maintenance, execution components, evaluation, and reporting.

An obvious question is, where will all the money and people come from to do this big job of planning? The answer is that the starting phase will have to be done by adjusting our present forces and budget. We hope that a successful beginning will generate accelerated support and appropriations. Much time and efficiency can be gained just by reducing the intensity and amount of time spent in handling complaints, disagreements, petitions, appeals, and court cases.

One thing is certain: we cannot afford to sit still with our present system and wait for problems to go away. We have to move out aggressively, learning from our past mistakes and applying our newfound interdisciplinary expertise in the proper place. Throughout the early stages, the public has been overwhelmingly behind this new approach to multiple-use planning. We have every reason to believe that public support will grow even stronger as we progress into unit planning. We look forward with optimism. We are confident of success.

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